Land Disposal of Sewage Sludge

Volume III

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RESEARCH REPORTS

These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of the Environment, and contracts with municipalities, research institutions and industrial organizations.

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by

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ABSTRACT

This report covers runoff studies with fall, winter and spring applied sewage sludge, and field rate and source of sludge studies with bromegrass on a loam soil and with corn on a loam, a sandy loam and a clay loam soil. A greenhouse trial with different rates and sources of sludge on two soils at three pH levels is also reported. Fluid digested sewage sludges from calcium oxide treatment of Newmarket sewage, aluminum sulphate treatment of Kitchener sewage and ferric chloride treatment of North Toronto sewage were used. Chemical analyses of the sludge, soil nitrogen, crop yields and nutrient and metal content of crops are presented along with microbial studies of the sludge and the crops grown. Detailed descriptions of the soils used are also presented.

In runoff studies, losses of nitrogen and nutrients were low in 1974, lower than 1973. One runoff event immediately following fall sludge application resulted in appreciable losses of nutrients, metals and COD.

In the field, crops responded to sewage sludge, responses being similar in most cases to those from chemical fertilizers. In one trial, where soil structure was a problem, sludges produced appreciably higher yields than chemical fertilizers. In the greenhouse, sludge at high rates of application caused salinity problems when the soils were not leached. Salinity is not expected to cause problems in the field in Ontario.

About twice as much nitrogen was required from sludges as from ammonium nitrate to produce a particular yield. At higher rates of sludge application, levels of nitrate toxic to animals were approached.

Sludges increased sodium bicarbonate soluble ("plant available") phosphorus quite markedly, and this effect was greatest with calcium sludge.

Cadmium, nickel and zinc concentrations in crops increased appreciably with additions of sludge high in metals. Greenhouse studies provide some evidence that these metals become more available to plants with time after sludge applications.

Chemical soil tests for plant available metals are under investigation. At this time, acetic acid appears to hold promise as an extractant of nickel under Ontario conditions.

In field soils, nitrate accumulated to a greater extent under corn than under grass. More nitrate was produced by sludges containing a larger portion of their nitrogen in ammonium form. Nitrate concentrations in soil were high in 1974 with less evidence of movement than in 1973, probably due to the lower rainfall in July and August.

Extraction, electron microprobe and X-ray analyses show that the iron in iron sludge is crystalline. Where sludges have been applied to the soil surface, calcium, aluminum and iron all appear to be moving into the soil, but calcium moved the farthest, up to 12 inches in two years.

RESUME

Le présent rapport traite des études sur le ruissellement des boues épandues en automne, en hiver et au printemps; il y est également question des études de la quantité et de la provenance des boues utilisées sur des terres grasses recouvertes de brome et de maïs, ainsi que sur les terres grasses sablonneuses et les terres grasses argileuses recouvertes de maïs. On y mentionne aussi une expérience en serre avec deux types de sols àtrois niveaus de pH, à l'aide de quantités variables de boues d'origine différente. Des boues liquides de la digestion des déchets obtenus par les traitements à l'oxyde de calcium (Newmarket), au sulfate d'aluminium (Kitchener) et au chlorure ferrique (North Toronto) ont été utilisées. En plus de présenter des analyses chimiques des boues, les rendements des récoltes, les teneurs en azote dans le sol, en métaux et en éléments nutritifs dans les cultures, le rapport donne les résultats d'études microbiennes ayant porté sur les boues et les cultures.

L'étude du ruissellement a révélé que, en 1974, les quantités d'azote et d'éléments nutritifs perdus étaient faibles, plus faibles qu'en 1973. En une circonstance, immédiatement après l'application de boues en automne, il y a eu entraînement d'assez grandes quantités d'éléments nutritifs et de métaux, et réduction importante de la demande chimique d'oxygène (DCO).

Sur le terrain, les cultures ont réagi aux applications de boues d'une façon semblable, dan la plupart des cas, aux engrais chimiques. Dans un cas particulier, où la composition du sol posait des problèmes, les boues se sont révélées plus efficaces que les engrais chimiques. Dans les serres, l'utilisation de grandes quantités de boues a accru la salinité des sols lorsque ces derniers n'étaient pas lessivés. Toutefois, on ne s'attend pas à ce que cette salinité suscite de difficultés dans les champs de l'Ontario.

Pour l'obtention d'un rendement donné, les boues ont eu besoin d'environ deux fois plus d'azote que le nitrate d'ammonium. Les niveaux toxiques des nitrates à l'égard des animaux ont presque été atteints lorsque l'on a augmenté le taux d'application des boues.

Les boues ont accru de façon assez marquée la quantité de phosphore soluble dans le bicarbonate de sodium, (assimilable par les plantes) et ce sont les boues riches en calcium qui ont donné les plus fort accroissement.

L'application de boues riches en métaux a fait augmenter d'une façon assez considérable les teneurs en cadmium, en nickel et en zinc dans les cultures. Les études effectuées dans les serres ont montré que, avec le temps, ces métaux deviennent de plus en plus assimilables par les plantes.

L'extraction des métaux du sol est actuellement à l'étude. L'acide acétique semble beaucoup promettre comme extracteur du nickel, dans les conditions prévalant en Ontario.

On remarque que les nitrates s'accumulent mieux dans les champs de maïs que dans les champs d'herbe. On a constaté également que les boues contenant de l'azote surtout sous forme ammoniacale produisaient de plus grandes quantités de nitrates. En 1974, année au cours de laquelle il y a eu moins de transport qu'en 1973, probablement en raison des faibles quantités de pluie tombées en juillet et en août, les concentrations de nitrates dans les sols étaient fortes cette année-là.

L'extraction, les analyses aux rayons X et les microsondes électroniques nous montrent que les fer des boues riches en fer a une structure cristalline. Là où l'on a répandu des boues à la surface du sol, le calcium, l'aluminium et le fer ont semblé pénétrer dans les sol, mais le calcium est celui qui y a pénétré le plus en profondeur, soit 12 pouces en deux ans.

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1. INTRODUCTION

This volume covers work done by the Department of Land Resource Science at the University of Guelph on land disposal of sewage sludge for Environment Canada and the Ontario Ministry of the Environment under project No. 72-5-17, contracted by the Department of Supplies and Services, and covers the period from April 1, 1974 to March 31, 1975.

In general, the research program is proceeding on schedule.

The 1974 season was a difficult one for growing crops in the field. The spring was unusually rainy, with fewer days available for sludge application, tillage and seeding than normal, resulting in later seeding than was desirable, particularly at the Milton site. A shortage of soil moisture towards the end of the season added to the problems.

Although many of the results reported are still preliminary there are several trends developing which made this year's work more interesting than in 1973.

2. GENERAL OBJECTIVES

The objective of this research is to determine maximum rates of sewage sludge application which can be used on agricultural soils without contaminating subsurface water with nitrate nitrogen and surface waters with elements or organisms pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

3. RUNOFF

3.1 Objectives

This section of the sludge project was designed to determine rates of sewage sludge which may be safely applied to certain slopes at specified times of the year.

3.2 Experimental

3.2.1 Design

Runoff was measured at the Elora Research Station in imperfect to poorly drained sandy clay loam soils with systematic tile drains. Field plots, 0.025 ac (0.01 hectare) on 2% and 6% slopes with suitable edging and runoff collection devices were installed in the fall of 1972. Fluid iron precipitated sludge from the North Toronto sewage treatment plant was applied to separate plots each November, January and May.

Rates of application, based on the nitrogen content of the sludge, were 178 lb N/ac (200 kg N/ha) and 712 lb N/ac (800 kg N/ha) on the 2% slope, and 178 lb N/ac (200 kg N/ha) on the 6% slope. On each slope, the treatment without sludge received 100 lb N/ac (112 kg N/ha) as NH_4NO_3 in the spring. Each treatment was replicated twice.

After each runoff event the volumes of water collected were measured, samples taken and tanks emptied.

The spring sludge and fertilizer applications were made on May 3, 1974 and ploughing and corn planting was completed by May 14, 1974. The corn was harvested on October 24, 1974.

3.2.2 Water analysis

Soluble nitrogen and phosphorus in the water samples were determined directly using an automated analytical technique after passing through a 0.45μ filter. To determine total nitrogen and phosphorus, the water samples were digested with H_2SO_4-H_2O_2 (Thomas et al, 1967), and then the concentration was determined using an automated analytical technique.

The metals: Cd, Cu, Ni, Pb and Zn, were determined by atomic absorption after the water samples were passed through a 0.45μ filter, chelated with APDC* and extracted with MIBK**. On a total sample Cd, Cu, Ni, Pb, and Zn were extracted with aqua regia, and then the concentrations were determined by atomic absorption.

Mercury content of filtered (0.45μ) water samples was determined by flameless atomic absorption (Hamm and Stewart, 1973) after oxidation of the organic mercurials with potassium permanganate and potassium persulphate. Sediment collected on the filters was digested using low temperature aqua regia before mercury determination.

3.3 Results and Discussion

3.3.1 Crop yield

Germination was normal and after thinning to 20,000 plants per acre on July 7, the corn was harvested on October 24, and the yields per acre (ha) were calculated (Table 1). On the average, the highest yields (98 bu/ac) were obtained on the plots treated with the lower rate of sludge on the 2% slope. Intermediate yields were obtained from the higher rate of sludge on the 2% slope (85.8 bu/ac) and from the commercial fertilizer (check) treatments (79.5 bu/ac); the lowest yield (75.3 bu/ac) occurred on the 6% slope. These results contrast with results obtained in 1973 when the highest rate of sludge application gave the greatest yield. In 1974, the yields on the plots treated with the low rate of sludge ranged 7-41% higher than in 1973, while the high rate of sludge application yielded only 88% of that in 1973.

3.3.2 Precipitation and runoff losses

Total precipitation for the period January to December 1974 was 31.27 inches (794.1 mm); this was 2.22 inches (56.4 mm) below the 30 year average (Table 2). Months in which precipitation was above the 30 year average were January, April, May, June and November, while July, August and October were markedly less than average.

Between January and May there were eight runoff events (Table 3) mostly resulting from rainfall. During the summer months, there were only two runoff events, the one on May 17 following 2.02 inches of rain

---

* Pyrrolidine carbodithioc acid ammonium salt

** Methyl isobutyl ketone

(Table 4). The only runoff event in the fall period occurred after the fall sludge application on November 20 (Table 5). This occurred because the liquid of the sludge augmented the 1.1 inches of rainfall received on that occasion.

The volumes of runoff collected during the year are indicated in Tables 6, 7 and 8, and the total for the year in Table 9. The greatest amount of runoff was collected from the plot treated with sludge in the fall on the 6% slope. With this exception, the volumes of runoff over all the treatments and slopes are very similar.

The losses of total and soluble nitrogen and phosphorus are shown in Tables 6, 7, 8, 10, 11 and 12, and the yearly total in Tables 9 and 13. In general, the highest nitrogen losses were from those plots which had received sludge at the beginning of the winter period. However, a large amount of nitrogen was lost from the plot treated with the highest rate of sludge in the fall; this was due to a runoff event coinciding with a sludge application. Losses from the plots which had been treated with sludge in the spring were comparable with the losses from the check plots. This results from both a lower incidence of runoff, and ploughing of the plots following the spring sludge application, burying the sludge beneath the soil surface.

Phosphorus losses were extremely low with, in general, no marked differences between sludge treatments and check plots. The highest phosphorus loss occurred in the fall period, again as a result of a runoff event coinciding with sludge application.

The soluble heavy metal losses were, in general, very small (Tables 14, 15, 16 and 17). On the 6% slope, the losses of all soluble metals were greatest following winter sludge application (Table 17) and were of a similar magnitude to the losses from the high sludge treatment on the 2% slope. In the case of the acid extractable metals, however, (Tables 18, 19, 20, and 21) the greatest losses were from the plots on the 6% slope, which had received sludge in the fall, and were about twice those of the check plots (Table 21). On the 2% slope, the losses from sludge treated plots were similar to those from the check plots. However, sizeable losses of all the metals occurred in a runoff event which coincided with the fall (1974) sludge application. The fact that only the acid extractable metals showed marked increases on this occasion was the result of the presence of a considerable quantity of suspended solid material in the runoff water.

An estimate of the amount of organic material present in runoff water is given by the value of the chemical oxygen demand (Tables 22, 23, 24 and 25). At the 200 kg N/ha rate of application the sludge treatments showed only slightly greater values than the check plots on either slope. However, the COD value for the 800 kg N/ha rate of sludge applied in the fall showed a marked increase and this was the result of a runoff event coinciding with the sludge application date. This result correlated with increased amounts of acid extractable metals and was due to solid material suspended in the runoff water.

3.4 Conclusions

The rainfall pattern during the year was somewhat unusual in that May and June were exceptionally wet while July and August were very dry; the total precipitation only slightly exceeded the 30 year average. Eleven runoff events occurred during the year, and in general the nitrogen losses were low, with the highest amounts being lost from plots which had been treated with sludge at the beginning of the winter period.

Phosphorus losses remained low throughout the period. Heavy metal losses were very low and there were no great differences between treatments, with the exception of greater losses of acid extractable metals on the 6% slope. The COD values were also low and did not differ markedly between treatments.

The coincidence of a runoff event and the fall sludge application resulted in elevated values of losses of nitrogen, phosphorus, acid extractable metals and COD.

3.5 Literature Cited

Hamm, J.W. and J.W.B. Stewart. 1973. A simplified procedure for the determination of total mercury in soils. Comm. Soil Sci. Plant Anal. 4: 233-240.

Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and antomated procedures for nitrogen, phosphorus, and potassium analyses of plant material using a single digestion. Agron. J. 59: 240-243.

TABLE 1. Yields of Corn (shelled grain) in 1974.

Slope and treatment		kg/ha	lb/ac
6% slope			
200 kg N	Fall	5148	4596
	Winter	4987	4453
	Spring	5050	4510
	Check	5196	4639
2% slope			
200 kg N	Fall	7037	6283
	Winter	6822	6091
	Spring	5880	5251
800 kg N	Fall	5673	5065
	Winter	5385	4808
	Spring	6254.	5584
	Check	5486	4898

TABLE 2. Monthly and Cumulative Precipitation for the Elora Area.

Month	January 1974-December 1974				30 Year Average			
	Monthly total		Cumulative total		Monthly total		Cumulative total	
	in	(mm)	in	(mm)	in	(mm)	in	(mm)
January	3.17	80.5	3.17	80.5	2.79	70.8	2.79	70.8
February	2.35	59.7	5.52	140.2	2.24	56.9	5.03	127.7
March	2.86	72.6	8.38	212.8	2.48	63.0	7.51	190.7
April	3.52	89.4	11.90	302.2	2.70	68.6	10.21	259.3
May	4.83	122.7	16.73	424.9	3.10	78.7	13.31	338.0
June	3.91	99.3	20.64	524.2	3.00	76.2	16.31	414.2
July	0.91	23.1	21.55	547.3	3.10	78.7	19.41	492.9
August	0.67	17.0	22.22	564.3	3.10	78.7	22.51	571.6
September	2.41	61.2	24.63	625.5	3.00	76.2	25.51	647.8
October	1.31	33.3	25.94	658.8	2.79	70.8	28.30	718.5
November	3.73	94.7	29.67	753.5	2.70	68.6	31.00	787.2
December	1.60	40.6	31.27	794.1	2.49	63.2	33.49	850.4

TABLE 3. Rainfall in Winter Period, Elora. January 23 - May 2, 1974.

Day of Month	January		February		March		April		May	
	in	mm	in	mm	in	mm	in	mm	in	mm
1			0.13	3.3	0.07	1.8	0.58	14.8		
2							0.01	0.3	0.02	0.5
3							0.89	22.7		
4					1.47	37.4	___	___		
5					___	___	0.02	0.5		
6			0.22	5.6			0.16	4.1		
7							0.06	1.5		
8					0.28	7.1				
9					0.03	0.7				
10			0.13	3.3						
11			0.02	0.5			0.07	1.8		
12							0.21	5.3		
13										
14							0.30	7.6		
15					0.14	3.6				
16			0.03	0.8	0.06	1.5				
17										
18			0.38	9.7	0.23	5.9				
19			0.25	6.4						
20					0.05	1.3				
21			0.60	15.3	0.08	2.0				
22			0.34	8.6	0.04	1.0	0.71	18.1		
23	□	□	0.01	0.3	0.10	2.5	0.06	1.5		
24					0.04	1.0				
25					0.06	1.5				
26	0.81	20.6			0.05	1.3				
27	0.02	0.5								
28	0.02	0.5	0.24	6.1			0.35	8.9		
29										
30					0.16	4.1	0.10	2.5		
31	0.06	1.5								
Monthly Total	0.91	23.1	2.35	59.9	2.86	72.7	3.52	89.6	0.02	0.5
Cumulative Total			3.26	82.8	6.12	155.4	9.64	244.9	9.66	245.4

□ Denotes a date of sludge application

___ Denotes a date in which a runoff event occurred

TABLE 4. Rainfall in Summer Period, Elora. May 3 - November 19, 1974.

Day of Month	May		June		July		August	
	in	mm	in	mm	in	mm	in	mm
1	↑	↑					0.14	3.6
2	|	|					0.05	1.3
3	$\boxed{0.01}$	$\boxed{0.2}$			___	___	0.04	1.0
4					0.17	4.32		
5	0.44	11.2						
6	0.02	0.5	0.12	3.0				
7								
8	0.67	17.0	0.04	1.0				
9	0.01	0.2					0.02	0.5
10								
11	0.64	16.3	0.10	2.5				
12	0.23	5.8	0.01	0.2			0.04	1.0
13								
14	0.55	13.9	0.23	5.8	0.05	1.3		
15			0.65	16.5				
16	2.02	51.3					0.02	0.02
17	___	___	0.10	2.5	0.19	4.8		
18			0.87	22.1				
19			0.28	7.1				
20			0.10	2.5				
21			0.01	0.2				
22								
23							0.01	0.2
24								
25			0.04	1.0	0.21	5.3		
26			0.09	2.28			0.14	3.6
27								
28	0.18		1.03	26.2	0.01	0.2		
29			0.24	6.1	0.25	6.3		
30					0.03	0.8	0.02	0.5
31	0.04						0.19	4.8
Monthly Total	4.59	116.4	3.91	99.3	0.91	23.1	0.67	17.0
Cumulative Total			8.50	215.7	9.40	238.8	10.08	255.8

☐ denotes a date of sludge application

___ denotes a date in which a runoff event occurred

TABLE 4. (continued)

Day of Month	September in	September mm	October in	October mm	November in	November mm
1			0.05	1.3		
2	0.33	8.4				
3					0.29	7.4
4					0.09	2.3
5					0.56	14.2
6			0.20	5.1		
7						
8			0.04	1.0		
9						
10						
11	0.26	6.6	0.06	1.5	0.52	13.2
12	0.02	0.5			0.13	3.3
13			0.33	8.4	0.23	5.8
14			0.25	6.4		
15					0.02	0.5
16			0.07	1.8	0.08	2.0
17	0.37	9.4				
18					0.01	0.2
19	0.10	2.5			0.28	7.1
20						
21						
22			0.02	0.5		
23						
24	0.09	2.3	0.03	0.8		
25	0.18	4.6				
26						
27	0.21	5.3				
28	0.64	16.3				
29	0.10	2.5	0.25	6.4		
30	0.11	2.8	0.01	0.2		
31						
Monthly Total	2.41	61.2	1.31	33.3	2.21	56.0
Cumulative Total	12.49	317.0	13.80	350.3	16.01	406.3

▭ denotes a date of sludge application

— denotes a date on which a runoff event occurred

TABLE 5. Rainfall in Fall Period, Elora. November 20, 1974 - January 14, 1975.

Day of Month	November in	November mm	December in	December mm	January in	January mm
1					0.04	1.0
2			0.13	3.3	0.10	2.5
3					0.60	15.2
4					0.30	7.6
5			0.02	0.5		
6					0.10	2.5
7			0.15	3.8		
8			0.06	1.5	0.23	5.8
9			0.10	2.5		
10					0.17	4.3
11			0.29	7.4		
12			0.02	0.5		
13					0.05	1.3
14					0.08	2.0
15			0.09	2.3		
16			0.01	0.2		
17			0.03	0.8		
18			0.06	1.5		
19			0.28	7.1		
20	$\boxed{1.10}$	$\boxed{27.9}$	0.03	0.8		
21	0.01	0.2				
22						
23	0.23	5.8	0.06	1.5		
24	0.04	1.0	0.09	2.3		
25	0.02	0.5	0.01	0.2		
26						
27	0.06	1.5				
28	0.06	1.5				
29						
30						
31			0.17	4.3		
Monthly Total	1.52	38.4	1.60	40.6	1.67	42.2
Cumulative Total			3.12	79.0	4.79	121.2

☐ Denotes a date of sludge application

— Denotes a date on which a runoff occurred

TABLE 6. Runoff in Winter Period, January 23, - May 2, 1974

Soluble nitrogen and phosphorus

Slope and treatment		Runoff		Nitrogen		Phosphorus	
		in	mm	lb/ac	kg/ha	lb/ac	kg/ha
6% slope							
200 kg N	Fall	6.01	152.9	1.70	1.91	0.25	0.28
	Winter	5.68	144.6	2.94	3.30	0.31	0.35
	Spring	6.08	154.7	0.38	0.42	0.12	0.13
	Check	5.37	136.7	0.52	0.59	0.11	0.13
2% slope							
200 kg N	Fall	5.29	134.6	1.21	1.36	0.14	0.32
	Winter	4.27	108.6	1.44	1.62	0.16	0.19
	Spring	4.08	103.8	0.59	0.67	0.12	0.13
800 kg N	Fall	5.55	141.2	3.05	3.42	0.19	0.21
	Winter	4.94	125.7	5.91	6.64	0.31	0.34
	Spring	5.23	133.1	0.87	0.98	0.13	0.15
	Check	4.18	106.4	0.61	0.69	0.10	0.14

TABLE 7. Runoff in Summer Period, May 3 - November 19, 1974.

Soluble nitrogen and phosphorus

Slope and treatment		Runoff		Nitrogen		Phosphorus	
		in	mm	lb/ac	kg/ha	lb/ac	kg/ha
6% slope							
200 kg N	Fall	1.28	32.5	0.27	0.30	0.09	0.10
	Winter	1.09	27.7	0.26	0.29	0.21	0.23
	Spring	0.70	17.8	0.14	0.16	0.04	0.05
	Check	1.11	28.2	0.24	0.27	0.15	0.17
2% slope							
200 kg N	Fall	0.85	21.6	0.12	0.13	0.07	0.08
	Winter	0.53	13.5	0.05	0.06	0.09	0.10
	Spring	0.96	24.4	0.11	0.12	0.12	0.13
800 kg N	Fall	1.07	27.2	0.13	0.15	0.11	0.12
	Winter	0.94	23.9	0.34	0.38	0.17	0.18
	Spring	0.95	24.1	0.15	0.17	0.11	0.13
	Check	0.73	18.5	0.12	0.14	0.06	0.06

TABLE 8. Runoff in Fall Period, November 20, 1974 - January 14, 1975.

Soluble nitrogen and phosphorus

Slope and treatment		Runoff		Nitrogen		Phosphorus	
		in	mm	lb/ac	kg/ha	lb/ac	kg/ha
6% slope							
200 kg N	Fall	0.15	3.8	0.71	0.79	0.19	0.22
	Winter						
	Spring						
	Check						
2% slope							
200 kg N	Fall	0.05	1.3	0.13	0.15	0.08	0.09
	Winter						
	Spring						
800 kg N	Fall	0.60	15.2	11.80	13.22	2.68	3.00
	Winter						
	Spring						
	Check	0.03	0.8	0.01	0.01	0.01	0.01

TABLE 9. Total Runoff Losses for Period January - December, 1974.

Soluble nitrogen and phosphorus

Slope and treatment		Runoff		Nitrogen		Phosphorus	
		in	mm	lb/ac	kg/ha	lb/ac	kg/ha
6% slope							
200 kg N	Fall	11.40	189.2	2.68	3.00	0.53	0.60
	Winter	6.77	172.3	3.20	3.59	0.52	0.58
	Spring	6.78	172.5	0.52	0.58	0.16	0.18
	Check	6.48	164.9	0.76	0.86	0.26	0.30
2% slope							
200 kg N	Fall	6.19	157.5	1.46	1.64	0.29	0.49
	Winter	4.80	122.1	1.49	1.68	0.25	0.29
	Spring	5.04	128.2	0.70	0.79	0.24	0.26
800 kg N	Fall	6.62	183.6	14.98	16.79	2.98	3.33
	Winter	5.88	149.6	6.25	7.02	0.48	0.52
	Spring	6.18	157.2	1.02	1.04	0.24	0.28
	Check	4.94	124.9	0.73	0.84	0.17	0.21

TABLE 10. Runoff in Winter Period, January - December, 1974.

Total nitrogen and phosphorus

Slope and treatment		Runoff		Nitrogen		Phosphorus	
		in	mm	lb/ac	kg/ha	lb/ac	kg/ha
6% slope							
200 kg N	Fall	6.01	152.9	3.36	3.77	0.89	1.00
	Winter	5.68	144.6	5.62	6.31	1.46	1.64
	Spring	6.08	154.7	2.44	2.74	0.73	0.82
	Check	5.37	136.7	3.25	3.65	1.00	1.12
2% slope							
200 kg N	Fall	5.29	134.6	2.15	2.41	0.76	0.85
	Winter	4.27	108.6	2.26	2.54	0.46	0.52
	Spring	4.11	103.8	1.22	1.37	0.45	0.51
800 kg N	Fall	7.55	141.2	4.59	5.16	0.75	0.84
	Winter	4.94	125.7	7.22	8.12	0.73	0.81
	Spring	5.23	133.1	1.99	2.23	0.47	0.53
	Check	4.18	106.4	1.50	1.69	0.34	0.38

TABLE 11. Runoff in Summer Period, May 3 - November 19, 1974.

Total nitrogen and phosphorus

Slope and treatment		Runoff		Nitrogen		Phosphorus	
		in	mm	lb/ac	kg/ha	lb/ac	kg/ha
6% slope							
200 kg N	Fall	1.28	32.5	2.64	2.96	0.36	0.39
	Winter	1.09	27.7	1.96	2.20	0.64	0.71
	Spring	0.70	17.8	0.91	1.02	0.21	0.24
	Check	1.11	28.2	1.60	1.80	0.58	0.66
2% slope							
200 kg N	Fall	0.85	21.6	1.24	1.40	0.35	0.39
	Winter	0.53	13.5	0.71	0.80	0.36	0.41
	Spring	0.96	24.4	1.27	1.42	0.38	0.43
800 kg N	Fall	1.07	27.2	1.33	1.50	0.49	0.55
	Winter	0.94	23.9	2.08	2.34	0.64	0.72
	Spring	0.95	24.1	1.46	1.64	0.42	0.52
	Check	0.73	18.5	1.01	1.14	0.25	0.28

TABLE 12. Runoff in Fall Period, November 20, 1974 - January 14, 1975.

Total nitrogen and phosphorus

Slope and treatment		Runoff		Nitrogen		Phosphorus	
		in	mm	lb/ac	kg/ha	lb/ac	kg/ha
6% slope							
200 kg N	Fall	0.15	3.8	0.71	0.79	0.19	0.22
	Winter						
	Spring						
	Check						
2% slope							
200 kg N	Fall	0.05	1.3	0.13	0.15	0.08	0.09
	Winter						
	Spring						
800 kg N	Fall	0.60	15.2	11.79	13.21	2.68	3.00
	Winter						
	Spring						
	Check	0.03	0.8	0.02	0.03	0.01	0.01

TABLE 13. Total Runoff in Period, January - December, 1974.

Total nitrogen and phosphorus

Slope and treatment		Runoff		Nitrogen		Phosphorus	
		in	mm	lb/ac	kg/ha	lb/ac	kg/ha
6% slope							
200 kg N	Fall	11.40	189.2	6.71	7.52	1.44	1.61
	Winter	6.77	172.8	7.58	8.51	2.10	2.35
	Spring	6.78	172.5	3.35	3.76	0.94	1.06
	Check	6.48	164.9	4.85	5.45	1.58	1.78
2% slope							
200 kg N	Fall	6.19	157.5	3.52	3.96	1.19	1.33
	Winter	4.80	122.1	2.97	3.34	0.82	0.93
	Spring	5.04	128.2	2.49	2.79	0.83	0.94
800 kg N	Fall	6.62	186.6	17.71	19.87	3.92	4.39
	Winter	5.88	149.6	9.30	10.46	1.37	1.53
	Spring	6.18	157.2	3.45	3.69	0.89	1.05
	Check	4.94	124.9	2.53	2.86	0.60	0.67

TABLE 14. Soluble Metals in Runoff, Winter Period, January 23 - May 2, 1974.

Slope and treatment		Cu	Ni	Cd	Pb	Zn	Hg
				kg/ha x 10^{-3} (lb/ac x 10^{-3})			
6% slope							
200 kg N	Fall	6.91 (6.2)	2.69 (2.4)	0.46 (0.4)	11.22 (10.1)	62.27 (56.0)	0.15 (0.13)
	Winter	13.07 (11.8)	2.18 (1.9)	0.58 (0.5)	16.99 (15.3)	87.15 (78.4)	0.14 (0.13)
	Spring	3.89 (3.5)	1.01 (0.9)	0.16 (0.1)	15.57 (14.0)	48.28 (43.5)	0.15 (0.13)
	Check	4.81 (4.3)	0.68 (0.6)	0.27 (0.2)	5.49 (4.9)	23.36 (21.0)	0.14 (0.13)
2% slope							
200 kg N	Fall	10.15 (9.1)	1.35 (1.2)	0.13 (0.1)	8.13 (7.3)	31.15 (28.0)	0.27 (0.24)
	Winter	7.64 (6.9)	3.28 (2.9)	0.32 (0.3)	14.19 (12.8)	30.03 (27.0)	0.11 (0.09)
	Spring	6.26 (5.6)	1.04 (0.9)	0.21 (0.2)	6.77 (6.1)	31.28 (28.2)	0.10 (0.09)
800 kg N	Fall	10.65 (9.6)	2.13 (1.9)	0.28 (0.2)	9.94 (8.9)	46.84 (42.2)	0.14 (0.13)
	Winter	23.39 (21.1)	4.43 (3.9)	0.38 (0.3)	17.70 (15.9)	34.77 (31.3)	0.38 (0.34)
	Spring	8.03 (7.2)	2.68 (2.4)	0.27 (0.2)	11.37 (10.2)	33.46 (30.1)	0.40 (0.36)
	Check	6.41 (5.8)	1.60 (1.4)	0.21 (0.2)	13.89 (12.5)	32.06 (28.9)	0.43 (0.38)

TABLE 15. Soluble Metals in Runoff, Summer Period, May 3 - November 19, 1974.

Slope and treatment		Cu		Ni		Cd		Pb		Zn		Hg	
		kg/ha x 10^{-3} (lb/ac x 10^{-3})											
6% slope													
200 kg N	Fall	2.2	(2.0)	<0.02	(<0.02)	<0.02	(<0.02)	<0.02	(<0.02)	<0.03	(<0.03)	0.02	(0.02)
	Winter	2.4	(2.1)	0.03	(0.3)	<0.02	(<0.02)	<0.2	(<0.2)	0.1	(0.1)	0.3	(0.3)
	Spring	2.8	(2.5)	0.03	(0.03)	<0.02	(<0.02)	2.8	(3.5)	0.3	(0.3)	0.1	(0.1)
	Check	1.9	(1.7)	<0.02	(<0.02)	<0.02	(<0.02)	<0.2	(<0.2)	2.1	(1.9)	0.4	(0.4)
2% slope													
200 kg N	Fall	4.1	(3.7)	0.2	(0.2)	0.02	(0.02)	<0.2	(<0.2)	1.6	(1.4)	0.6	(0.5)
	Winter	0.9	(0.8)	<0.02	(<0.02)	<0.02	(<0.02)	<0.2	(<0.2)	0.19	(0.16)	0.6	(0.5)
	Spring	1.6	(1.4)	<0.02	(<0.02)	<0.02	(<0.02)	0.9	(0.8)	0.7	(0.6)	0.2	(0.2)
800 kg N	Fall	1.9	(1.7)	<0.02	(<0.02)	<0.02	(<0.02)	<0.2	(<0.2)	0.1	(0.1)	0.2	(0.2)
	Winter	1.7	(1.5)	<0.02	(<0.02)	<0.02	(<0.02)	<0.2	(<0.2)	0.1	(0.1)	0.1	(0.1)
	Spring	2.1	(1.9)	<0.02	(<0.02)	<0.02	(<0.02)	5.2	(4.6)	0.1	(0.1)	0.2	(0.2)
	Check	1.1	(1.0)	0.1	(0.1)	0.02	(0.02)	0.2	(0.2)	1.2	(1.1)	<0.1	(<0.1)

TABLE 16. Soluble Metals in Runoff, Fall Period, November 20, 1974 - January 14, 1975.

Slope and treatment		Cu		Ni		Cd		Pb		Zn		Hg	
		kg/ha x 10^{-3} (lb/ac x 10^{-3})											
6% slope													
200 kg N	Fall	0.3	(0.3)	0.2	(0.2)	<0.02	(<0.02)	0.36	(0.32)	0.38	(0.34)	<0.03	(<0.03)
	Winter												
	Spring												
	Check												
2% slope													
200 kg N	Fall	<0.1	(<0.1)	0.1	(0.1)	<0.02	(<0.02)	0.10	(0.09)	0.13	(0.12)	<0.02	(<0.02)
	Winter												
	Spring												
800 kg N	Fall	2.7	(2.4)	0.9	(0.8)	<0.02	(<0.02)	3.4	(3.0)	1.5	(1.3)	0.1	(0.1)
	Winter												
	Spring												
	Check	<0.01	(<0.01)	0.02	(0.02)	<0.02	(<0.02)	0.13	(0.12)	0.1	(0.9)	<0.01	(<0.01)

TABLE 17. Total Soluble Metals in Runoff, January - December, 1974.

Slope and treatment		Cu		Ni		Cd		Pb		Zn		Hg	
		kg/ha x 10^{-3} (lb/ac x 10^{-3})											
6% slope													
200 kg N	Fall	9.11	(8.2)	2.89	(2.6)	0.46	(0.4)	11.58	(10.44)	62.65	(56.3)	0.35	(0.33)
	Winter	15.47	(13.9)	2.48	(2.2)	0.58	(0.5)	16.99	(15.3)	87.25	(78.5)	0.44	(0.43)
	Spring	6.69	(6.0)	1.04	(0.9)	0.16	(0.1)	18.35	(16.5)	48.58	(43.8)	0.25	(0.23)
	Check	6.71	(6.0)	0.68	(0.6)	0.27	(0.2)	5.49	(4.9)	25.46	(22.9)	0.54	(0.53)
2% slope													
200 kg N	Fall	14.25	(12.8)	1.65	(1.5)	0.15	(0.1)	8.23	(7.4)	32.88	(29.5)	0.87	(0.74)
	Winter	8.54	(7.7)	3.28	(2.9)	0.32	(0.3)	14.19	(12.8)	30.22	(27.2)	0.71	(0.59)
	Spring	7.86	(7.0)	1.04	(0.9)	0.21	(0.2)	7.67	(6.7)	31.98	(28.8)	0.30	(0.29)
800 kg N	Fall	15.25	(13.7)	3.03	(2.7)	0.28	(0.2)	13.34	(11.90)	48.44	(43.8)	0.44	(0.43)
	Winter	25.09	(22.6)	4.43	(3.9)	0.38	(0.3)	17.70	(15.9)	34.87	(31.4)	0.48	(0.44)
	Spring	10.13	(9.1)	2.68	(2.4)	0.27	(0.2)	16.57	(14.8)	33.56	(30.2)	0.60	(0.56)
	Check	7.51	(6.58)	1.72	(1.5)	0.23	(0.2)	14.22	(12.82)	33.26	(30.0)	0.43	(0.38)

TABLE 18. Acid Extractable Metals in Runoff, Winter Period, January 23 - May 2, 1974.

Slope and treatment		Cu		Ni		Cd		Pb		Zn		Hg	
		kg/ha x 10^{-3} (lb/ac x 10^{-3})											
6% slope													
200 kg N	Fall	42.28	(38.1)	28.44	(25.6)	2.46	(2.2)	80.72	(72.6)	247.5	(222.8)	0.46	(0.41)
	Winter	52.29	(47.1)	21.78	(19.6)	2.90	(2.6)	112.57	(101.3)	246.9	(222.2)	0.44	(0.39)
	Spring	24.92	(22.4)	19.46	(17.5)	1.56	(1.4)	56.06	(50.5)	143.3	(128.9)	0.31	(0.28)
	Check	44.64	(40.2)	37.77	(33.9)	1.92	(1.7)	92.72	(83.4)	240.4	(216.4)	0.27	(0.24)
2% slope													
200 kg N	Fall	12.87	(11.6)	10.38	(9.7)	1.35	(1.2)	20.99	(18.9)	71.1	(63.9)	0.68	(0.61)
	Winter	14.74	(13.3)	9.82	(8.8)	1.09	(0.9)	40.94	(36.8)	68.8	(61.9)	0.33	(0.29)
	Spring	13.03	(11.7)	11.47	(10.3)	1.04	(0.9)	39.09	(35.2)	82.4	(74.2)	0.10	(0.09)
800 kg N	Fall	19.87	(17.9)	19.16	(17.2)	1.86	(1.5)	36.90	(33.2)	109.3	(98.4)	0.43	(0.38)
	Winter	31.61	(28.4)	9.48	(8.5)	1.51	(1.4)	26.55	(23.9)	99.3	(89.4)	0.76	(0.68)
	Spring	14.05	(12.6)	15.39	(13.8)	1.34	(1.2)	24.09	(21.7)	96.4	(86.8)	0.54	(0.48)
	Check	11.76	(10.6)	8.55	(7.7)	1.07	(0.9)	34.73	(31.3)	76.4	(68.8)	0.75	(0.68)

TABLE 19. Acid Extractable Metals in Runoff, Summer Period, May 3 - November 19, 1974.

Slope and treatment		Cu	Ni	Cd	Pb	Zn	Hg
				kg/ha x 10^{-3} (lb/ac x 10^{-3})			
6% slope							
200 kg N	Fall	73.7 (65.8)	112.6 (100.5)	4.5 (4.0)	203.4 (181.6)	363.9 (324.9)	0.4 (0.4)
	Winter	61.5 (54.9)	90.6 (80.9)	3.4 (3.0)	174.3 (155.6)	206.3 (184.2)	0.7 (0.6)
	Summer	24.9 (22.2)	49.3 (44.0)	1.2 (1.1)	82.0 (73.2)	128.4 (114.6)	0.2 (0.2)
	Check	55.4 (49.5)	89.3 (79.7)	3.1 (2.8)	145.5 (129.9)	137.0 (122.3)	0.7 (0.6)
2% slope							
200 kg N	Fall	8.5 (7.6)	29.6 (26.4)	1.3 (1.2)	53.2 (47.5)	56.4 (50.4)	0.1 (0.1)
	Winter	3.2 (2.9)	13.6 (12.1)	0.2 (0.2)	33.4 (29.8)	19.5 (17.4)	0.1 (0.1)
	Summer	7.5 (6.7)	15.6 (13.9)	1.7 (1.5)	69.7 (62.2)	33.6 (30.0)	0.3 (0.3)
800 kg N	Fall	20.7 (18.5)	51.0 (45.5)	1.7 (1.5)	91.5 (91.7)	110.1 (98.3)	0.4 (0.4)
	Winter	20.9 (18.7)	33.5 (29.9)	20.2 (18.0)	86.9 (77.6)	115.1 (102.8)	0.4 (0.4)
	Summer	24.4 (21.8)	57.1 (51.0)	1.2 (1.1)	93.4 (83.4)	132.6 (118.4)	0.3 (0.3)
	Check	16.9 (15.1)	44.0 (39.3)	1.6 (1.4)	93.2 (83.2)	96.0 (85.7)	<0.1 (<0.1)

TABLE 20. Acid Extractable Metals in Runoff, Fall Period, November 20, 1974 - January 14, 1975.

Slope and treatment		Cu	Ni	Cd	Pb	Zn	Hg
		kg/ha x 10^{-3} (lb/ac x 10^{-3})					
6% slope							
200 kg N	Fall	87.7 (78.3)	8.6 (7.7)	3.2 (2.9)	125.6 (112.1)	146.9 (131.2)	1.0 (0.9)
	Winter						
	Spring						
	Check						
2% slope							
200 kg N	Fall	5.5 (4.9)	1.3 (1.2)	0.2 (0.2)	19.0 (17.0)	10.9 (9.7)	0.6 (0.5)
	Winter						
	Spring						
800 kg N	Fall	375.6 (335.4)	35.3 (31.5)	11.5 (10.3)	600.9 (536.5)	661.0 (590.2)	7.7 (6.9)
	Winter						
	Spring						
	Check	<0.1 (<0.1)	0.4 (0.4)	<0.1 (<0.1)	1.7 (1.5)	2.8 (2.5)	<0.1 (<0.1)

TABLE 21. Total Acid Extractable Metals in Runoff, January - December, 1974.

Slope and treatment		Cu	Ni	Cd	Pb	Zn	Hg
		kg/ha x 10^{-3} (lb/ac x 10^{-3})					
6% slope							
200 kg N	Fall	203.6 (182.2)	149.6 (133.8)	10.2 (9.1)	409.7 (366.3)	758.3 (678.9)	1.86 (1.71)
	Winter	113.8 (102.0)	112.4 (100.5)	6.3 (5.6)	286.9 (256.9)	453.2 (406.4)	1.14 (0.99)
	Spring	49.8 (44.6)	68.9 (61.5)	2.8 (2.5)	138.1 (123.7)	271.7 (243.5)	0.51 (0.48)
	Check	100.0 (89.5)	123.1 (113.6)	5.0 (4.5)	238.2 (213.3)	377.4 (338.7)	0.97 (0.84)
2% slope							
200 kg N	Fall	26.9 (24.1)	41.3 (37.3)	2.9 (2.4)	93.2 (83.4)	138.4 (124.0)	1.38 (1.21)
	Winter	17.9 (16.2)	23.4 (20.9)	1.3 (1.1)	74.3 (66.6)	88.3 (79.3)	0.43 (0.39)
	Spring	20.5 (18.4)	27.1 (24.2)	2.7 (2.4)	108.8 (97.4)	116.0 (104.2)	0.40 (0.39)
800 kg N	Fall	416.2 (371.8)	105.5 (94.2)	15.1 (13.3)	729.3 (651.4)	880.4 (786.9)	8.53 (7.68)
	Winter	52.5 (47.1)	42.9 (38.4)	21.7 (19.4)	113.5 (101.5)	214.4 (192.2)	1.16 (1.08)
	Spring	38.4 (34.4)	72.5 (64.8)	2.5 (2.3)	117.5 (105.1)	229.0 (205.2)	0.84 (0.78)
	Check	28.7 (25.7)	52.9 (47.4)	2.7 (2.3)	129.6 (116.0)	175.2 (157.0)	0.75 (0.68)

TABLE 22. Total COD in Runoff Water, Winter, 1974.

Slope and treatment		kg/ha	lb/ac
6% slope			
200 kg N	Fall	88.9	80.0
	Winter	182.1	163.9
	Spring	97.3	87.6
	Check	180.3	162.3
2% slope			
200 kg N	Fall	102.6	91.6
	Winter	70.9	63.8
	Spring	73.7	66.3
800 kg N	Fall	121.0	108.9
	Winter	113.2	101.8
	Spring	119.8	107.8
	Check	68.0	61.2

TABLE 23. Total COD in Runoff Water, Summer, 1974.

Slope and treatment		kg/ha	lb/ac
6% slope			
200 kg N	Fall	348.8	311.4
	Winter	421.2	376.0
	Spring	343.5	306.7
	Check	273.4	244.1
2% slope			
200 kg N	Fall	102.6	91.6
	Winter	54.6	48.7
	Spring	266.8	238.2
800 kg N	Fall	232.3	207.4
	Winter	225.0	200.9
	Spring	177.4	158.4
	Check	103.6	92.5

TABLE 24. Total COD in Runoff Water, Fall, 1974.

Slope and treatment		kg/ha	lb/ac
6% slope			
200 kg N	Fall	81.0	72.3
	Winter		
	Spring		
	Check		
2% slope			
200 kg N	Fall	30.3	27.1
	Winter		
	Spring		
800 kg N	Fall	678.3	605.6
	Winter		
	Spring		
	Check	1.4	1.2

TABLE 25. Total COD in Runoff Water, January - December, 1974.

Slope and treatment		kg/ha	lb/ac
6% slope			
200 kg N	Fall	518.7	463.7
	Winter	603.3	539.9
	Spring	440.8	394.3
	Check	453.7	406.4
2% slope			
200 kg N	Fall	235.5	210.3
	Winter	125.5	112.5
	Spring	340.5	304.5
800 kg N	Fall	1031.6	921.9
	Winter	338.2	302.7
	Spring	297.2	266.2
	Check	173.0	154.9

4. FIELD RATE AND SOURCE EXPERIMENTS

4.1 Objectives

The objective of the field rate and source experiments is to determine the rate of three chemically treated sludges which may be safely used on typical Ontario soils without adversely affecting crop yields, or nitrate and heavy metal contents.

4.2 Materials and Methods

4.2.1 General

Experiments are in progress on three soils: (1) Conestoga loam to sandy clay loam on the Elora Research Station, (2) Caledon loamy sand on the Cambridge (Hespeler) Research Station, (3) Oneida clay loam on the farm of David Sargent near Milton. At the Elora Research Station one experiment is in progress with corn (*Zea Mays L.*) as the crop and one with bromegrass (*Bromis inermis Leyess*). Only corn is being grown at the Cambridge and Milton sites.

The following sources of nitrogen have been used:

1) ammonium nitrate;
2) fluid digested calcium treated sludge from the Newmarket treatment plant;
3) fluid digested aluminum sulphate treated sludge from the Point Edward (1973) and Kitchener (1974) treatment plants; and,
4) fluid digested ferric chloride treated sludge from the North Toronto treatment plant.

The rates of nitrogen application each year from the sludges are:

1) 178 lb N/ac (200 kg/ha)
2) 356 lb N/ac (400 kg/ha)
3) 712 lb N/ac (800 kg/ha)
4) 1424 lb N/ac (1600 kg/ha).

The rates of nitrogen application each year from ammonium nitrate are:

1) 0 lb N/ac
2) 89 lb N/ac (100 kg/ha)
3) 178 lb N/ac (200 kg/ha)
4) 356 lb N/ac (400 kg/ha).

There are four nitrogen sources, four rates, and three replications, resulting in a total of 48 plots for each trial. The corn plot size is 15' x 25' (4.57 x 7.62 m) and the bromegrass plot size is 8' x 20' (2.44 x 6.09 m).

Analyses of samples from the three sludges obtained at different times through the season are presented in Tables 26 and 27.

4.2.2 Bromegrass, Elora

The grass trial was laid out on an established stand of bromegrass on the Elora research station on Conestoga sandy clay loam in the spring of 1973. Potassium chloride supplying 50 lb of K_2O/ac (47 kg/ha) was broadcast on all plots in the spring of 1973 and supplying 97 lb of K_2O/ac (90 kg K/ha) in the spring of 1974. Eighty-three lb P_2O_5/ac (40 kg P/ha) as 46% superphosphate was broadcast on the plots which received NH_4NO_3 fertilizer in the spring of 1973 and 80 lb P_2O_5/ac (39 kg P/ha) in the spring of 1974. The NH_4NO_3 was also broadcast on the specified plots and at the specified rates on May 9 in 1973. In 1974, the sludges and ammonium nitrate were applied to the grass plots during three periods, with each application being one-third of the total annual rate. The dates of nitrogen and sludge applications to grass in 1974 were as follows:

First application:	Ammonium Nitrate May 1
	Ca - sludge April 26
	Al - sludge May 2
	Fe - sludge May 1
Second application:	Ammonium Nitrate June 21
	Ca - sludge June 20
	Al - sludge June 21
	Fe - sludge June 24
Third application:	Ammonium Nitrate July 25
	Ca - sludge July 26
	Al - sludge July 26
	Fe - sludge July 25

In 1974, the bromegrass was harvested on June 17, July 22 and August 26. Drought conditions in July and August undoubtedly decreased the yields from the second and third harvests in 1974.

4.3 Results and Discussion

Plant material from all trials was analysed for nutrient and metal content but, in general, only those data showing statistically significant treatment effects at 0.05 probability are presented in this report. Corn seedlings were only analysed for macronutrients, not for micronutrients and metals.

4.3.1 Bromegrass

Total amounts of nutrients and metals applied in the sludge in 1973 and 1974 are presented in Table 28. The sludge resulting from calcium treatment of sewage caused a marked increase in sodium bicarbonate extractable ("available") phosphorus in the surface soil (Table 29). The calcium sludge also raised the soil pH (Table 30).

Total yields of bromegrass from the grass experiment as harvested in three consecutive cuttings in 1974 are presented in Tables 29, 30, 31 and 32. Yield increased with each increase in rate of ammonium nitrate. The sludges resulting from aluminum sulphate and ferric chloride produced similar yields to ammonium nitrate but at twice the rate of nitrogen. The sludge resulting from lime treatment of sewage produced lower yields at low rates of application, but higher yields at higher rates of application, than the other sludges. This effect was less marked in the third than in the first and second cuttings. In 1973, the aluminum sludge from Point Edward produced lower yields than the other two sludges. The aluminum sludge used in 1974 was from Kitchener and produced yields very similar to those with the iron sludge. Any undesirable effects of the Point Edward sludge apparently dissipated before the 1974 growing season.

Total nitrogen concentrations in all three cuts of bromegrass were markedly increased by all sources of nitrogen (Tables 35, 36 and 37) and the nitrate nitrogen concentration (Tables 38, 39 and 40). The total nitrogen concentration in bromegrass tended to be lower with the calcium sludge than with the other sludges, except at the highest rate of application in the third cut. This appears to follow the yield patterns, suggesting that the differences in yield between sludges may be largely due to differences in nitrogen availability. Nitrate nitrogen approached toxic levels for animals in the highest rate of sludge application. Sludges applied at 800 lb N/ac produced approximately the same yield as 400 lb N/ac for ammonium nitrate but somewhat lower total and nitrate N concentrations.

Phosphorus concentrations in the bromegrass were reduced by all sources of nitrogen (Tables 41, 42 and 43). At low rates of application the sludges increased the phosphorus concentrations over those with the lowest rate of ammonium nitrate. The calcium sludge at low rates of application resulted in higher concentrations of phosphorus than the other sludges and a similar trend was apparent in 1973, confirming the higher concentrations of "available" phosphorus measured in the soil (Table 29). The effects of treatment on phosphorus concentration in the bromegrass were greatest in the first cut and least in the third cut.

Potassium concentrations in bromegrass were reduced by all sources of nitrogen (Tables 44, 45 and 46). The iron sludge resulted in slightly lower potassium concentrations than the other two sludges although the three sludges supplied about the same amount of potassium.

Calcium concentrations in bromegrass were increased by nitrogen application regardless of source (Table 47) but were not affected by source of sludge.

Magnesium concentrations in the bromegrass, in general, decreased with increasing nitrogen application (Tables 50, 51 and 52). Although the calcium sludge supplied more manganese (Table 28) than the other sludges it resulted in the lowest manganese concentration in the forage. This is probably due to the increased soil pH with calcium sludge (Table 30).

Iron concentrations in the first and third cuts of bromegrass were affected by sludge additions but the effects do not follow a clear pattern. The iron sludge resulted in higher iron concentrations in bromegrass.

Aluminum concentrations of bromegrass only showed treatment differences in the third cut (Table 55). In the third cut, nitrogen decreased aluminum concentration and calcium sludge resulted in lower aluminum concentrations than the other sludges, probably because of the higher soil pH. This is similar to the pattern with manganese.

Copper concentrations in bromegrass were increased by nitrogen application (Tables 56, 57 and 58). The calcium sludge produced slightly lower copper concentrations in the grass than the other sludges, probably a reflection of the smaller amounts of copper added with the calcium sludge (Table 28).

Zinc concentrations in all three cuts of bromegrass were increased by nitrogen application (Tables 59, 60 and 61). The sludges appeared to increase zinc content more than equivalent rates of nitrogen from ammonium nitrate. Differences in zinc concentration of bromegrass between sludges were statistically significant in the first two cuts but small and not consistent.

Cadmium concentrations in bromegrass were, in general, increased by nitrogen application (Tables 62, 63 and 64). The concentrations of cadmium were quite low and no higher with sludge than with ammonium nitrate. The lime sludge resulted in lower cadmium concentrations than the other sludges, probably because of the higher soil pH with calcium sludge.

Chromium concentrations in the third cut of bromegrass were reduced slightly by nitrogen application (Table 65). The aluminum sludge resulted in higher chromium concentrations than the other sludges, probably a reflection of the much larger additions of chromium.

Nickel concentrations in the third cut of bromegrass were significantly higher with the aluminum sludge than with the other sludges (Table 66), probably a reflection of the higher nickel content in this sludge.

Mercury concentrations in the first cut of bromegrass were significantly decreased by sludge application (Table 67). The data do not show clearly whether ammonium nitrate can produce the same effect.

4.3.2 Corn

Field operations on the three corn trials are outlined in Table 68, and the total amounts of nutrients and metals applied during 1973 and 1974 to each of the three sites in the sewage sludges are presented in Tables 69, 70 and 71.

The 1974 season started with a wet spring which resulted in a slight delay in seeding at Elora and an extended delay at Milton, (optimum seeding date is May 10-15). July, August and September were quite dry but the drought did not appear to affect the crop at Elora to any marked extent. The corn at Cambridge grew very well early in the season but on this sandy soil water became limiting and yields were somewhat reduced. The Milton crop suffered from the combined effects of late planting and an earlier drought than the other sites. Plants showed serious drought stress at a very early stage with the result that the final crop was uneven and very poor. Frost on September 23 ended the growing season at Milton but the corn at Elora was very close to maturity at that time and the Cambridge corn was ready for harvest.

Corn seedlings at the three sites were not all sampled at the same stage of development but some effort was made to sample at the six-leaf stage. The sludge appeared to produce at least as rapid early growth as chemical fertilizers and the iron sludge produced greater weights per plant than the other sludges, although this was only significant at the Cambridge site (Tables 72, 73 and 74). A similar pattern was shown in rate of emergence of seedlings at Cambridge as measured by the number of plants emerged at 17 days (Table 75). At Elora the rate of maturity as measured by the percentage of plants silked at 73 days also showed the iron sludge treatments to be more advanced (Table 76). There was some tendency for the two middle rates of sludge to produce greater weights of seedlings than the lowest or highest rate, although this was only significant at Elora (Table 72).

Grain yields were similar with ammonium nitrate as with the sludges at Elora and Cambridge (Tables 77 and 78) but much higher with the sludges at Milton (Table 79). The soil at Milton has a serious structural problem which appeared to affect the crop adversely in 1974. It seems possible that the sludges increased yields by improving soil structure. There was an appreciable response to nitrogen from ammonium nitrate, and what appears to be a response to nitrogen from sludge at both Elora and Milton, but a much smaller response at Cambridge.

Corn stover yields, in general, followed similar patterns to those with grain yields although differences were less marked (Tables 80, 81 and 82).

Lodging of corn was significantly affected by treatment at Milton (Table 83) but the reasons for differences are not readily apparent.

Soil pH sampled in the fall of 1973 was highest with the calcium sludge at all three sites (Tables 84, 85 and 86). There was a tendency for the other two sludges to lower soil pH, but less than one quarter as much as similar rates of nitrogen from ammonium nitrate.

Total nitrogen concentrations in corn seedlings responded to nitrogen treatments at Cambridge but not at Elora (Tables 87 and 88). At Elora and Cambridge nitrogen concentration in seedlings was lower with the calcium sludge than with the other two sludges. Total nitrogen concentrations in corn grain were affected by nitrogen rates. About twice as much total nitrogen was required from sludge as from ammonium nitrate to produce a particular nitrogen concentration at Elora and Cambridge (Table 89), but about four times as much sludge nitrogen is required at Milton (Table 92).

Nitrate nitrogen in the corn stover increased with nitrogen rates at Elora, Cambridge and Milton (Tables 90 and 91) and was higher with the iron sludge than with the other sludges at Milton (Table 91). In the corn stover, nitrogen concentration was as high with sludge as with equal rates of nitrogen from ammonium nitrate at Elora and Cambridge, but not at Milton (Table 90). The greater yields with sludge at Milton are apparently not due to nitrogen, but to a dilution of the nitrogen in the plants.

Soil phosphorus extracted by sodium bicarbonate from the surface soil increased with increasing rates of sludge application at all three sites and was much higher with the calcium sludge than with the other sludges at each site (Table 93, 94 and 95). This difference occurred in spite of an appreciably smaller amount of phosphorus added in the calcium sludge (Tables 69, 70 and 71).

Phosphorus concentrations in corn seedlings were significantly affected by treatment at all three sites but differences were small and did not follow a consistent pattern (Tables 96, 97 and 98). Phosphorus concentration in corn grain was slightly higher with the calcium sludge than with the other two sludge at Elora (Table 99).

Potassium concentrations in corn seedlings at all three sites (Tables 100, 101 and 102) and in corn stover at Elora and Milton (Tables 103 and 104) were lower with the calcium sludge than with one or both of the other sludges, in spite of larger additions of potassium with the calcium sludge at Elora and Cambridge (Tables 70 and 71). The lower potassium concentrations in plants with the calcium sludge were due either to competition for uptake with the very large amounts of calcium added in the calcium sludge, or to the slightly greater amounts of magnesium. Increasing rates of sludge tended to increase potassium concentration in plant tissue (Tables 89, 90, 91, 92 and 93).

Calcium concentrations in corn seedlings and corn stover from Milton were highest with the calcium sludge (Tables 105 and 106) and increased with increasing rates of nitrogen from ammonium nitrate or sludge in corn stover at Cambridge and Milton (Tables 90 and 106).

Soil magnesium extracted by ammonium acetate (exchangeable magnesium) was affected by treatment at Elora and Milton, but there is no consistent pattern across sites (Tables 107 and 108).

Magnesium concentrations in corn seedlings from Elora decreased with increasing rates of sludge (Table 109). Magnesium concentrations in corn seedlings from Cambridge (Table 110) and in corn stover from Elora (Table 111) were higher with the calcium sludge than with the other two sludges.

Iron concentrations in corn stover were only affected by treatment at Milton (Table 112) which showed higher iron from the aluminum sludge. Iron concentrations in corn stover were very high and the samples were undoubtedly contaminated from soil splashing up on the corn stalks, particularly where the stalks lodged. Iron concentrations in corn grain from Elora were highest with the 200 kg N/ha rate of sludge (Table 89).

Aluminum concentrations in corn stover from Milton increased with increasing rates of nitrogen from ammonium nitrate, but decreased with increasing rates of sludge (Table 91). As in the case of iron, soil contamination is believed to have added appreciably to aluminum concentrations measured in the corn stover.

Copper concentrations in the corn stover from Milton increased with increasing rate of nitrogen from ammonium nitrate or sludge, but concentrations reached as high levels with ammonium nitrate as with sludge (Table 91).

Chromium concentrations in corn stover from Cambridge and Milton were higher with the aluminum sludge than with other sources of nitrogen (Table 113). This was no doubt due to the much larger amounts of chromium added in the aluminum sludge.

Lead concentrations in corn stover from Milton were highest with calcium sludge and lowest with iron sludge; ammonium nitrate and aluminum sludge were intermediate (Table 113). Concentration is inversely related to amount added from the sludges, in this case.

Mercury concentrations in corn stover from Milton were significantly higher with the iron sludge than with other treatments (Table 113). The amount of mercury added was greater with the iron sludge. In corn grain from Milton, mercury was lowest with the iron sludge (Table 114).

Nickel concentrations in corn stover from Milton increased with increasing rates of nitrogen from ammonium nitrate but decreased with increasing rate of nitrogen from sludge (Table 91). Nickel concentrations in corn stover from Elora were much higher with the highest rate of aluminum sludge than with any other treatment (Table 115). More nickel was added in the aluminum sludge (Table 69).

Zinc concentrations in corn stover increased with rate of nitrogen from ammonium nitrate at Elora and Cambridge (Tables 116 and 117) and in corn grain at Cambridge (Table 89). Zinc concentration in corn stover was doubled by increasing rates of sludge at Elora and Cambridge (Tables 116 and 117). Increases in zinc concentrations with increasing sludge rates were also observed in corn stover at Milton (Table 118) and in corn grain at Elora and Cambridge (Tables 119 and 89). The zinc concentration in corn stover at Elora, Cambridge and Milton, and in corn grain at Elora, were lower with the calcium sludge than with the other sludges (Tables 116, 117, 118 and 119).

For reference purposes the concentrations of nutrients and metals in corn grain and stover from treatments receiving approximately recommended rates of commerical fertilizers are presented in Tables 120 and 121. In the corn stover, aluminum and iron values are probably greatly overestimated due to contamination with soil.

TABLE 26. Chemical Composition of Sludges Obtained from Sewage Treatment Plants on Various Dates (fluid weight basis).

Sludge	Date	pH	D.M. %	N %	Sol N µg/g	Exch. N µg/g	P %	K %	Ca %	Mg %	Al %	Fe %	Na µg/g
Calcium New Market	24/4/74	7.1	13.9	.18	335	5	.12	.01	3.27	.05	.06	.11	139
	26/4/74	7.0	14.9	.18	338	50	.14	.02	3.58	.05	.06	.08	129
	23/5/74	7.2	7.6	.15	285	8	.08	.01	1.75	.03	.03	.06	134
	19/6/74	7.1	6.2	.14	374	14	.13	.01	1.35	.03	.02	.10	138
	25/7/74	7.2	6.7	.12	363	13	.09	.01	1.68	.04	.03	.06	150
	Average	7.1	9.9	.15	339	18	.11	.01	2.33	.04	.04	.08	138
Aluminum Sludge Kitchener	18/4/74	7.3	6.5	.28	1250	84	.19	.01	.65	.06	.16	.07	240
	1/5/74	7.4	3.7	.24	950	39	.13	.01	.35	.04	.13	.03	203
	8/5/74	7.2	6.7	.30	1175	90	.23	.01	.65	.05	.19	.07	221
	20/6/74	7.3	6.5	.31	1238	84	.21	.01	.73	.06	.22	.12	250
	25/7/74	7.4	3.5	.24	1041	37	.13	.01	.40	.04	.16	.04	350
	Average	7.3	5.4	.27	1131	67	.18	.01	.56	.05	.17	.07	253
Iron North Toronto	17/4/74	7.3	6.1	.30	825	51	.29	.01	.24	.04	.08	.45	158
	30/4/74	7.2	6.2	.30	913	87	.26	.01	.25	.04	.08	.43	149
	2/5/74	7.1	7.2	.33	950	73	.33	.01	.29	.04	.10	.52	158
	24/5/74	7.1	6.1	.30	900	53	.27	.01	.31	.04	.08	.40	146
	24/6/74	7.1	6.8	.30	913	63	.28	.02	.38	.05	.10	.54	150
	25/7/74	7.2	6.1	.30	819	63	.27	.02	.33	.04	.16	.51	128
	Average	7.2	6.4	.30	887	65	.28	.02	.30	.04	.10	.48	148

TABLE 27. Micronutrient and Metal Content of Sludges Obtained from Treatment Plants on Various Dates.

Sludge	Date	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn	B
				µg/g (fluid wt. basis)						
	24/4/74	.21	6.3	24	.17	53	2.8	17	56.99	1
	26/4/74	.15	4.8	22	.16	55	3.6	16	83.44	1
Calcium	23/5/74	.11	2.4	13	.11	33	1.5	10	33.21	1
New	19/6/74	.33	1.8	18	.17	42	1.5	11	50.00	2
Market	25/7/74	.38	1.5	14	.15	35	1.5	8	58.00	2
	Average	.24	3.35	18	.15	44	2.2	13	56.33	1
	18/4/74	.68	618	41	.15	16	31.2	28	308.75	2
	1/5/ 74	.28	370	20	.07	9	17.4	13	166.50	1
	8/5/ 74	.50	637	37	.27	16	30.2	24	301.50	2
Aluminum	20/6/74	.53	625	70	.23	18	26.0	24	375.00	2
Kitchener	25/7/74	.45	325	22	.12	9	13.3	13	200.00	3
	Average	.49	515	38	.17	14	23.6	21	270.35	2
	17/4/74	1.68	29.0	82	.98	25	2.4	119	164.70	1
	30/4/74	1.58	25.7	81	1.22	24	1.9	118	170.50	2
	2/5/74	1.94	33.8	97	1.58	29	2.2	144	205.20	1
Iron	24/5/74	1.53	25.6	82	1.46	24	1.8	113	170.80	1
North	21/6/74	1.88	22.5	95	1.90	26	2.3	133	188.00	2
Toronto	25/7/74	1.68	27.5	85	2.50	25	2.8	118	185.00	2
	Average	1.72	22.8	87	1.61	25	2.2	124	180.70	2

TABLE 28. Total Amounts of Various Nutrients and Metals in Sludges Applied in 1973 and 1974 at the Rate of 178 lb N/ac (200 kg/ha) on Elora Grass Plots.

	Calcium Sludge		Aluminum Sludge		Iron Sludge	
Constituents	lb/ac	kg/ha	lb/ac	kg/ha	lb/ac	kg/hg
Total N	356	400	356	400	356	400
Soluble N	81	91	125	141	107	120
Exch. N	4.5	5.0	7.2	8.1	12	14
Solids	20811	23384	9538	10717	8016	9007
P_2O_5	611		693		831	
P	267	300	303	341	363	408
K_2O	67		53		67	
K	28	32	22	25	28	32
Ca	5138	5773	500	562	354	398
Mg	115	129	63	71	58	65
Na*	36	40	36	42	16	18
Al	61	69	518	582	134	151
Fe	152	171	74	83	307	345
Cd	.09	.10	.08	.09	.20	.22
Cr	.61	.69	34	38	3.3	3.7
Cu	4.17	4.69	6.4	7.2	12	13
Hg	.04	.04	.03	.03	.18	.21
Mn	8.0	9.0	1.4	1.6	3.2	3.6
Ni	.43	.48	1.7	1.9	.33	.37
Pb	1.8	2.0	3.0	3.4	12	14
Zn	16	18	23	26	22	25
B*	.50	.56	.30	.34	.24	.28

* Sodium and B not determined in 1973. Values presented are based on 1974 analysis.

TABLE 29. Sodium Bicarbonate Extractable Phosphorus in Surface Soil (0-6 in) Elora Grass, Fall, 1973.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				µg/g		
0	(0)	11a				
89	(100)	10a				
178	(200)	6a	9a	7a	7a	8
356	(400)	6a	14a	8a	6a	9
712	(800)		30b	8a	11a	16
1424	(1600)		108b	12a	12a	44
Average**			40	9	9	19

CV=28%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source and rate of sludge and the source - rate interaction are significant effects at 0.01 probability by "F" test.

TABLE 30. pH in Soil Water Paste of Surface Soil (0-6 in). Elora Grass, Fall, 1973.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		Nitrogen Source				
0	(0)	7.2ab				
89	(100)	7.1ab				
178	(200)	7.3bc	7.1ab	7.1ab	7.1ab	7.1
356	(400)	7.3abc	7.4bc	7.3abc	7.3bc	7.3
712	(800)		7.5c	7.0ab	7.1ab	7.2
1424	(1600)		7.6c	7.1ab	6.9a	7.2
Average**			7.4	7.1	7.1	7.2

CV=2.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability and source - rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 31. Annual Dry Matter Yield of Bromegrass from Three Cuttings.* Elora, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source**				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
	dry matter - lb/ac (kg/ha)				
0 (0)	890 a (990)				
89 (100)	2750 bc (3080)				
178 (200)	4120 cf (4620)	2160 b (2420)	3220 cd (3600)	3060 cd (3430)	2810 (3150)
356 (400)	6030 h (6750)	3650 de (4090)	4820 g (5410)	4770 fg (5340)	4410 (4950)
712 (800)		6340 h (7100)	6060 h (6790)	6240 h (6990)	6210 (6960)
1424 (1600)		6990 i (7840)	6150 h (6896)	5960 h (6680)	6370 (7140)
Average**		4790 (5360)	5060 (5680)	5010 (5610)	4950 (5550)

*Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

**Rate of sludge and the source-rate interaction are significantly different at 0.05 probability by "F" test.

TABLE 32. Dry Matter Yield of First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source** Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
	dry matter - lb/ac (kg/ha)				
0 (0)	640 a (720)				
89 (100)	1800 bc (2010)				
178 (200)	2620 de (2940)	1320 b (1480)	2030 c (2280)	1880 bc (2110)	1740 (1950)
356 (400)	4040 fg (4530)	2140 cd (2400)	2960 e (3320)	2870 e (3220)	2660 (2980)
712 (800		3900 fg (4370)	4010 fg (4490)	4090 fg (4590)	4000 (4480)
1424 (1600)		4470 g (5010)	3990 fg (4470)	3790 f (4240)	4080 (4570)
Average		2960 (3310)	3250 (3640)	3160 (3540)	3120 (3500)

*Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

**Rate of sludge and source-rate interaction are significantly different at 0.05 probability by "F" test.

TABLE 33. Dry Matter Yield of Second Cut (July 22) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source**				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
	dry matter - lb/ac (kg/ha)				
0 (0)	180 a (200)				
89 (100)	650 bc (730)				
178 (200)	1210 fg (1360)	540 b (600)	840 cd (940)	920 de (1030)	770 (860)
356 (400)	1500 hi (1720)	1110 ef (1250)	1410 gh (1580)	1470 hi (1650)	1330 (1490)
712 (800)		1840 j (2070)	1520 hi (1710)	1660 ij (1860)	1680 (1880)
1424 (1600)		1690 ij (1890)	1320 fgh (1470)	1480 hi (1660)	1490 (1670)
Average		1296 (1450)	1271 (1430)	1380 (1550)	1320 (1480)

*Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

**Rate of sludge and source-rate interaction are significantly different at 0.05 probability by "F" test.

TABLE 34. Dry Matter Yield of Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
	dry matter - lb/ac (kg/ha)				
0 (0)	60 a (70)				
89 (100)	300 bc (340)				
178 (200)	280 b (320)	310 bc (340)	340 bcd (380)	260 b (290)	300 (340)
356 (400)	450 bcde (500)	400 bcde (450)	460 bcde (510)	430 bcde (480)	430 (480)
712 (800)		590 ef (660)	530 def (590)	490 cde (550)	530 (600)
1424 (1600)		840 g (940)	850 g (950)	690 fg (780)	790 (890)
Average		530 (600)	540 (610)	470 (520)	510 (580)

*Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

**Rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 35. Nitrogen Concentration in First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				% - N		
0	(0)	1.77ab				
89	(100)	1.72a				
178	(200)	2.10abc	1.90ab	1.88ab	1.82ab	1.87
356	(400)	2.72d	1.88ab	1.97ab	2.07abc	1.97
712	(800)		2.20bc	2.82d	2.65d	2.56
1424	(1600)		2.48cd	2.87d	2.87d	2.74
Average**			2.12	2.38	2.35	2.28

CV=10.5 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability and rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 36. Nitrogen Concentration in Second Cut (July 22) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
			% - N			
0	(0)	2.75a				
89	(100)	2.78a				
178	(200)	3.17bc	2.85ab	2.80a	2.65a	2.77
356	(400)	4.17e	2.93ab	3.38c	3.47c	3.26
712	(800)		3.78d	4.15e	4.17c	4.03
1424	(1600)		4.25e	4.37e	4.38e	4.33
Average**			3.45	3.68	3.67	3.60

CV=5.4%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at .05 probability and rates of sludge are significantly different at .01 probability by "F" test.

TABLE 37. Nitrogen Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				% - N		
0	(0)	2.92 a				
89	(100)	3.23b				
178	(200)	3.47cd	3.18b	3.10ab	3.07ab	3.12
356	(400)	4.05fg	3.28bc	3.83ef	3.65de	3.59
712	(800)		4.17g	4.17g	4.13g	4.16
1424	(1600)		4.48i	4.22gh	4.32hi	4.38
Average**			3.78	3.83	3.82	3.81

CV=3.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rate of sludge and the source-rate interaction are significant effects at 0.01 probability by "F" test.

TABLE 38. Nitrate Nitrogen Concentration in First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
0	(0)	0.000a		% - NO_3 - N		
89	(100)	0.000a				
178	(200)	0.011a	0.003a	0.003a	0.000a	0.002
356	(400)	0.047bc	0.000a	0.000a	0.000a	0.000
712	(800)		0.027ab	0.068c	0.031ab	0.042
1424	(1600)		0.066c	0.077cd	0.101d	0.081
Average			0.024	0.037	0.033	0.031

CV=69%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 39. Nitrate Nitrogen Concentration in Second Cut (July 22) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
			$\% - NO_3 - N$			
0	(0)	0.015a				
89	(100)	0.007a				
178	(200)	0.010a	0.011a	0.003a	0.009a	0.008
356	(400)	0.085bc	0.014a	0.021ab	0.021ab	0.018
712	(800)		0.070abc	0.103cd	0.103cd	0.092
1424	(1600)		0.159d	0.088c	0.136cd	0.128
Average			0.063	0.054	0.067	0.061

CV=68%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 40. Nitrate Nitrogen Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		% - NO_3 - N				
0	(0)	0.007ab				
89	(100)	0.013ab				
178	(200)	0.009ab	0.000a	0.005a	0.013ab	0.006
356	(400)	0.049c	0.000a	0.016ab	0.007ab	0.008
712	(800)		0.025abc	0.032bc	0.031bc	0.030
1424	(1600)		0.091d	0.108d	0.091d	0.097
Average			0.029	0.040	0.035	0.035

CV=44 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 41. Phosphorus Concentration on First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				% - P		
0	(0)	0.30ef				
89	(100)	0.26abcd				
178	(200)	0.25ab	0.32f	0.28bcde	0.28bcde	0.29
356	(400)	0.25abc	0.32f	0.26abcd	0.29de	0.29
712	(800)		0.28cde	0.27abcde	0.26abcd	0.27
1424	(1600)		0.24a	0.25abc	0.29de	0.26
Average**			0.29	0.26	0.28	0.28

CV=6.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source and rate of sludge and the source-rate interaction are significant effects at 0.01 probability by "F" test.

TABLE 42. Phosphorus Concentration in Second Cut (July 22) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				% -P		
0	(0)	0.36cde				
89	(100)	0.31a				
178	(200)	0.31a	0.39fg	0.39fg	0.38ef	0.39
356	(400)	0.31a	0.41g	0.35bcd	0.38def	0.38
712	(800)		0.38def	0.35bc	0.35bcd	0.36
1424	(1600)		0.34bc	0.33ab	0.34bc	0.34
Average**			0.38	0.36	0.36	0.37

CV=3.9 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources and rates of sludge are significantly different at 0.01 probability and the source-rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 43. Phosphorus Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% - P		
0	(0)	0.29abcd				
89	(100)	0.27a				
178	(200)	0.27a	0.33fg	0.32defg	0.29abcd	0.32
356	(400)	0.28ab	0.34g	0.31bcdefg	0.31bcdefg	0.32
712	(800)		0.33efg	0.30abcde	0.30abcdef	0.31
1424	(1600)		0.32defg	0.29abc	0.31cdefg	0.31
Average**			0.33	0.30	0.31	0.31

CV=5.2%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability by "F" test.

TABLE 44. Potassium Concentration in First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				% - K		
0	(0)	2.38def				
89	(100)	2.21cde				
178	(200)	1.90b	2.52f	2.30def	2.30def	2.37
356	(400)	1.54a	2.41ef	2.20cde	2.12bcd	2.24
712	(800)		2.18cde	2.14bcde	1.91b	2.08
1424	(1600)		1.63a	2.28cdef	2.01bc	1.98
Average**			2.19	2.23	2.09	2.17

CV=6.8%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rate of sludge and the source-rate interaction are significant effects at 0.01 probability by "F" test.

TABLE 45. Potassium Concentration in Second Cut (July 22) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				% - K		
0	(0)	2.67f				
89	(100)	2.18cd				
178	(200)	1.75a	2.49ef	2.18cd	2.33de	2.34
356	(400)	1.48a	2.07bcd	2.00abc	1.82ab	1.96
712	(800)		1.74a	1.88ab	1.78a	1.80
1424	(1600)		1.79ab	1.81ab	1.82ab	1.81
Average			2.02	1.97	1.94	1.98

CV=7. 6%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of Sludge are significantly different at 0.01 by "F" test.

TABLE 46. Potassium Concentration on Third Cut (August 26) Bromegrass. Elora, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				% - K		
0	(0)	2.27h				
89	(100)	1.79f				
178	(200)	1.47cd	2.11hi	1.84fg	2.04gh	2.00
356	(400)	1.03a	1.75ef	1.68ef	1.43bcd	1.62
712	(800)		1.35bc	1.46cd	1.23b	1.35
1424	(1600)		1.57de	1.88fg	1.43bcd	1.63
Average**			1.69	1.72	1.53	1.65

CV=6.8 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source and rate of sludge and the source-rate interaction are significant effects at 0.01 probability by "F" test.

TABLE 47. Concentration of Various Constituents in Bromegrass at Different Levels of Nitrogen Application. Average Concentration for the Three Sludges. 1974.

Constituent	Source of Nitrogen	Rate of Nitrogen lb/ac (kg/ha)						Average
		0 (0)	89 (100)	178 (200)	356 (400)	712 (800)	1424 (1600)	
				Concentration - %				
Ca	NH_4NO_3	.39	.43	.48	.51			.45
First Harvest	Sludge**			.41	.39	.47	.53	.45
Ca	NH_4NO_3*	.63	.71	.62	.76			.68
Second Harvest	Sludge**			.61	.62	.72	.77	.68
Ca	NH_4NO_3	1.04	1.09	1.07	1.02			1.06
Third Harvest	Sludge**			1.08	1.00	.98	1.11	1.05
Mg	NH_4NO_3**	.23	.27	.27	.35			.28
Second Harvest	Sludge**			.25	.27	.32	.33	.29
				Concentration µg/g				
Fe	NH_4NO_3	65	56	58	61			60
Second Harvest	Sludge**			55	57	60	63	59

* Effect of Nitrogen rates significant at 0.05 probability by "F" test.

** Effect of Nitrogen rates significant at 0.01 probability by "F" test.

TABLE 48. Magnesium Concentration in First Cut (June 17) of Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge ** Average
				% - Mg		
0	(0)	0.16abc				
89	(100)	0.16abc				
178	(200)	0.17abc	0.16abc	0.17abc	0.16ab	0.16
356	(400)	0.21ef	0.16abc	0.14a	0.17bcd	0.16
712	(800)		0.16abc	0.19cde	0.20def	0.18
1424	(1600)		0.22f	0.19cde	0.21ef	0.20
Average **			0.17	0.17	0.18	0.18

CV=8.3 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.01 probability and source-rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 49. Magnesium Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		% - Mg				
0	(0)	0.29a				
89	(100)	0.36bcd				
178	(200)	0.40defg	0.32ab	0.35bc	0.34bc	0.34
356	(400)	0.43gh	0.34bc	0.38cdef	0.38cde	0.37
712	(800)		0.40efg	0.40efg	0.46h	0.42
1424	(1600)		0.45h	0.42fgh	0.45h	0.44
Average**			0.38	0.39	0.41	0.39

CV=5.8%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.05 probability and rates are significantly different at 0.01 probability by "F" test.

TABLE 50. Manganese Concentration in First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		Nitrogen Source				
		(µg Mn/g)				
0	(0)	55h				
89	(100)	55h				
178	(200)	51gh	45defg	45defg	46efg	45
356	(400)	48fg	40cde	42cdef	48fg	43
712	(800)		33ab	38bcd	42cdef	38
1424	(1600)		30a	37bc	42cdef	36
Average**			37	41	44	41

CV=8.4 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source and rate of sludge are significant effects at 0.01 probability by "F" test.

TABLE 51. Manganese Concentration in Second Cut (July 22) Bromegrass Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(μg Mn/g)		
0	(0)	72f				
89	(100)	67ef				
178	(200)	57cd	52bcd	59de	57cd	56
356	(400)	58cd	50abc	50abc	52bcd	50
712	(800)		43a	53bcd	51abcd	49
1424	(1600)		45ab	50abc	60de	51
Average**			48	53	55	52

CV = 8.2 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability and rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 52. Manganese Concentration in Third Cut (August 26) Bromegrass Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(μg Mn/g)		
0	(0)	98fg				
89	(100)	116hi				
178	(200)	119i	87ef	103gh	106ghi	99
356	(400)	80de	75cde	79de	80de	78
712	(800)		52ab	55ab	66bcd	58
1424	(1600)		49a	61abc	75cde	62
Average**			66	75	82	74

CV=10%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source and rate of sludge are significant effects at 0.01 probability by "F" test.

TABLE 53. Iron Concentration in First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(µg Fe/g)		
0	(0)	52a				
89	(100)	49a				
178	(200)	44a	47a	42a	52a	47
356	(400)	56a	47a	45a	44a	45
712	(800)		45a	54a	56a	52
1424	(1600)		52a	56a	77b	62
Average**			48	49	57	51

CV=14 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources and rates of sludge are significantly different at .01 probability and the source-rate interactions are significantly different at .05 probability by "F" test.

TABLE 54. Iron Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(µg Fe/g)		
0	(0)	86bcd				
89	(100)	77abc				
178	(200)	78abc	90bcd	80abc	112d	94
356	(400)	79abc	82abc	75abc	88bcd	82
712	(800)		73ab	78abc	103cd	85
1424	(1600)		76abc	76abc	56a	69
Average**			80	77	90	82

CV=18%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rate of sludge and the source-rate interaction are significant effects at .05 probability by "F" test.

TABLE 55. Aluminum Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		Nitrogen Source				
				(μg Al/g)		
0	(0)	27cde				
89	(100)	22bcde				
178	(200)	20abcd	26cde	31e	29de	29
356	(400)	18abc	21abcd	21abcd	21abcd	21
712	(800)		16ab	22bcde	22bcde	20
1424	(1600)		12a	24bcde	22bcde	19
Average**			19	24	24	22

CV=22%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at .05 probability and rates of sludge are significantly different at .01 probability by "F" test.

TABLE 56. Copper Concentration in First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(µg Cu/g)		
0	(0)	5a				
89	(100)	8bc				
178	(200)	7bc	8bc	7ab	7abc	7
356	(400)	8bcde	7bc	9cdef	8bc	8
712	(800)		8bcd	11g	10defg	10
1424	(1600)		10efg	11g	10fg	11
Average**			8	10	9	9

CV=12.2 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.05 probability and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 57. Copper Concentration in Second Cut (July 22) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		Nitrogen Source				
		(µg Cu/g)				
0	(0)	7a				
89	(100)	8ab				
178	(200)	8abc	8abc	9abc	9abc	9
356	(400)	11d	9abc	11d	10cd	10
712	(800)		10bcd	14fg	12de	12
1424	(1600)		13ef	15g	15g	14
Average**			10	12	12	11

CV=9.9 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source and rate of sludge effects are significant at 0.01 probability by "F" test.

TABLE 58. Copper Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(μg Cu/g)		
0	(0)	8a				
89	(100)	8a				
178	(200)	9a	9ab	9a	9ab	9
356	(400)	10ab	8a	11bc	9a	9
712	(800)		10ab	12c	11bc	11
1424	(1600)		12cd	14e	14de	13
Average**			10	11	11	11

CV=9.8%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source and rate of sludge are significant effects at 0.01 probability by "F" test.

TABLE 59. Zinc Concentration in First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(µg Zn/g)		
0	(0)	18a				
89	(100)	19a				
178	(200)	19ab	20ab	20ab	19ab	20
356	(400)	22bc	21ab	22bc	20ab	21
712	(800)		24cd	29f	26de	26
1424	(1600)		28ef	29ef	28ef	28
Average**			23	25	23	24

CV=8.1 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.05 probability and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 60. Zinc Concentration in Second Cut (July 22) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		(µg Zn/g)				
0	(0)	17a				
89	(100)	18ab				
178	(200)	21bc	21bc	21bc	22cd	21
356	(400)	24cde	22c	24cde	25def	23
712	(800)		27efg	29gh	28fg	28
1424	(1600)		32i	28fg	32hi	31
Average**			25	25	27	26

CV=6.9 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.01 probability and the source-rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 61. Zinc Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				(μg Zn/g)		
0	(0)	20a				
89	(100)	19a				
178	(200)	24bc	24bc	26bcd	24b	25
356	(400)	25bcd	26bcd	28de	28de	27
712	(800)		25bcd	28de	27cde	27
1424	(1600)		32f	30ef	32f	31
Average			27	28	28	28

CV=7.0%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 62. Cadmium Concentration in First Cut (June 17) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
					(µg Cd/g)	
0	(0)	0.067				
89	(100)	0.050				
178	(200)	0.163	0.150	0.017	0.067	0.078
356	(400)	0.100	0.050	0.084	0.067	0.067
712	(800)		0.017	0.100	0.134	0.084
1424	(1600)		0.070	0.100	0.117	0.096
Average			0.072	0.075	0.096	0.081

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* A number of cadmium values were below detection limits. Statistical analysis of these data were therefore not considered valid.

TABLE 63. Cadmium Concentration in Second Cut (July 22) Bromegrass. Elora, 1974.*

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(µg Cd/g)		
0	(0)	0.07ab				
89	(100)	0.07ab				
178	(200)	0.07ab	0.07ab	0.10abc	0.07ab	0.08
356	(400)	0.15cde	0.08abc	0.05a	0.13bcd	0.09
712	(800)		0.10abc	0.10abc	0.12abcd	0.11
1424	(1600)		0.10abc	0.18de	0.22e	0.17
Average**			0.09	0.11	0.13	0.11

CV=39 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significant at .05 probability and rates of sludge are significant at .01 probability by "F" test.

TABLE 64. Cadmium Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(µg Cd/g)		
0	(0)	0.13ab				
89	(100)	0.08ab				
178	(200)	0.12ab	0.07a	0.08ab	0.13ab	0.10
356	(400)	0.10ab	0.08ab	0.08ab	0.07a	0.08
712	(800)		0.12ab	0.18bc	0.12ab	0.14
1424	(1600)		0.07a	0.17abc	0.25c	0.16
Average**			0.08	0.13	0.14	0.12

CV=48 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources and rates of sludge are significant effects at 0.05 probability by "F" test.

TABLE 65. Chromium Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		(μg Cr/g)				
0	(0)	2.08abc				
89	(100)	1.83abc				
178	(200)	2.00abc	2.75bc	4.33d	2.17abc	3.08
356	(400)	1.58ab	2.08abc	2.92bc	2.08abc	2.36
712	(800)		1.33a	2.67abc	2.33abc	2.11
1424	(1600)		1.58ab	3.17cd	2.42abc	2.39
Average**			1.94	3.27	2.25	2.49

CV=30%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at .01 probability and rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 66. Nickel Concentration in Third Cut (August 26) Bromegrass. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				(μg Ni/g)		
0	(0)	1.0abc				
89	(100)	1.4cd				
178	(200)	1.2abcd	1.2abcd	1.2abcd	1.3abcd	1.2
356	(400)	1.0abc	1.5cd	1.4cd	0.8a	1.2
712	(800)		0.8ab	1.4cd	1.3bcd	1.2
1424	(1600)		1.3bcd	1.7d	1.1abc	1.7
Average**			1.2	1.4	1.1	1.2

CV=23%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge and the source - rate interaction are significant effects at 0.05 probability.

TABLE 67. Mercury Concentration in First Cut (June 17) Bromegrass, Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		µg Hg/g				
0	(0)	0.020abcd				
89	(100)	0.023cd				
178	(200)	0.024d	0.019abcd	0.018abcd	0.022bcd	0.020
356	(400)	0.018abcd	0.017abcd	0.015abc	0.015abc	0.016
712	(800)		0.018abcd	0.013a	0.017abcd	0.016
1424	(1600)		0.013a	0.014a	0.015abc	0.014
Average			0.017	0.015	0.017	0.016

CV=24%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 68. Field Operations on Rate and Source of Sludge Experiments with Corn, 1974.

Treatment or Description	Elora	Cambridge	Milton
Soil	Conestoga loam	Caledon loamy sand	Oneida clay loam
Plowed	April 1974	April 1974	November 1973
Calcium sludge applied	April 26	April 18	May 23
Alum sludge applied	May 2	April 19	May 9
Iron sludge applied	May 1	April 24	May 24
Phosphorus applied to ammonium nitrate treatments and disked in before seeding			
	104 lb P_2O_5/ac (50 kg P/ha)	No phosphorus required	no phosphorus or potassium
Potassium applied to all treatments and disked in before seeding.			
	97 lb K_2O/ac (90 kg K/ha)	49 lb K_2O (45 kg K/ha)	required
Corn hybrid	United 106	United 106	United 106
Corn seeded and 60 pounds 6-18-6 fertilizer per acre applied in a band with seed on all treatments.	May 21	May 10	June 6
Emerged plants counted	June 3	May 27	June 28
Stand thinned - 6-leaf stage	June 26	June 13	July 12
Final stand count	August 2	July 24	August 15
Final stand - plants/ac	22,000	16,000	22,000
Silks counted	August 2	July 24	August 15
Plant height measured to flag leaf	August 28	August 28	--
Grain harvested	October 10	September 24	October 18
Stover harvested	October 11	October 25	October 18

TABLE 69. Total Amounts of Various Nutrients and Metals in Sludges Applied in 1973 and 1974 at the Rate of 178 lb N/ac (200 kg/ha) on Elora Corn Plots.

Constituent	Calcium Sludge		Aluminum Sludge		Iron Sludge	
	lb/ac	kg/ha	lb/ac	kg/ha	lb/ac	kg/ha
Total N	356	400	356	400	356	400
Soluble N	116	130	124	139	106	119
Exch. N	8.1	9.1	7.1	8.0	13	15
Solids	21347	23909	9153	10251	7853	8795
P_2O_5	495		754		835	
P		241		367		407
K_2O	54		30		36	
K		50		28		34
Ca	5067	5675	385	431	338	379
Mg	126	141	65	73	54	60
Na*	26	30	30	34	18	20
Al	85	95	337	377	80	90
Fe	175	196	36	40	423	474
Cd	.04	.04	.07	.08	1.02	1.14
Cr	.63	.71	29.4	32.9	3.02	3.38
Cu	3.5	3.9	6.4	7.2	10.6	11.9
Hg	.03	.03	.03	.03	.16	.18
Mn	7.1	8.0	1.4	1.6	3.1	3.5
Ni	0.50	.56	1.6	1.8	.24	.27
Pb	2.4	2.7	2.4	2.7	12	14
Zn	16.1	18.0	18	20	21	24
B*	.20	.22	.14	.16	.24	.27

* Sodium and B not determined in 1973. Values presented are based on 1974 analysis.

TABLE 70. Total Amounts of Various Nutrients and Metals in Sludges Applied in 1973 and 1974 at the Rate of 178 lb N/ac (200 kg/ha) at Cambridge.

Constituent	Calcium Sludge		Aluminum Sludge		Iron Sludge	
	lb/ac	kg/ha	lb/ac	kg/ha	lb/ac	kg/ha
Total N	356	400	356	400	356	400
Soluble N	68	76	117	131	100	112
Exch. N	4.8	5.4	8.7	9.8	10	11
Solids	29077	22566	10235	11500	8038	9003
P_2O_5	614		745		890	
P		299		363		433
K_2O	36		24		28	
K		34		23		26
Ca	7091	7942	566	634	314	352
Mg	99	111	76	85	60	67
Na*	28	31	30	34	20	22
Al	69	77	1107	1240	84	94
Fe	139	156	109	122	464	520
Cd	.14	.15	.13	.15	.18	.20
Cr	1.5	1.7	41	46	2.9	3.3
Cu	5.0	5.6	6	7.4	11	12
Hg	.05	.06	.03	.03	.14	.16
Mn	8.9	10.0	1.6	1.8	3.5	3.9
Ni	.67	.75	2.1	2.4	.28	.31
Pb	3.4	3.8	3.3	3.7	12	13
Zn	20	22	25	28	22	25
B*	.20	.22	.26	29	12	14

* Sodium and B not determined in 1973. Values presented are based on 1974 analysis.

TABLE 71. Total Amounts of Various Nutrients and Metals in Sludges Applied in 1973 and 1974 at the Rate of 178 lb N/ac (200 kg/ha) at Milton.

Constituent	Calcium Sludge		Aluminum Sludge		Iron Sludge	
	lb/ac	kg/ha	lb/ac	kg/ha	lb/ac	kg/ha
Total N	356	400	356	400	356	400
Soluble N	72	81	116	130	109	122
Exch. N	6	6.7	8.6	9.6	10	11
Solids	12733	14261	11807	13224	8347	9348
P_2O_5	531		879		879	
P		259		431		440
K_2O	27		29		29	
K		24		27		27
Ca	4883	5469	582	652	363	407
Mg	88	99	83	93	60	67
Na*	32	36	26	29	18	20
Al	47	53	1699	1903	75	84
Fe	99	111	111	124	393	440
Cd	.09	0.10	.10	.11	.17	.19
Cr	.99	1.11	39	44	2.8	3.1
Cu	3.9	4.4	6.1	6.8	10.3	11.5
Hg	.03	.03	.04	.05	.18	.20
Mn	6.6	7.4	1.7	1.9	3.12	3.49
Ni	.45	.50	2.1	2.4	.28	.31
Pb	2.6	2.9	3.1	3.5	11.2	12.5
Zn	14	16	24	27	20	22
B*	.24	.27	.24	.27	.12	.13

* Sodium and B not determined in 1973. Values presented are based on 1974 andlysis.

TABLE 72. Corn Seedling Weight. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				g - Dry Matter		
0	(0)	8.48abcde				
89	(100)	5.99a				
178	(200)	7.11ab	7.16ab	10.14cdef	9.49bcdef	8.93
356	(400)	7.06ab	6.71ab	10.88ef	10.25cdef	9.28
712	(800)		8.50abcde	10.83ef	11.64f	10.32
1424	(1600)		7.55abc	7.94abcd	10.76def	8.75
Average			7.48	7.95	10.53	9.32

CV=17%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 73. Corn Seedling Weight. Cambridge, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		g - dry matter				
0	(0)	14.68a				
89	(100)	19.01bcde				
178	(200)	18.70bcde	15.79ab	17.94abcd	18.77bcde	17.50
356	(400)	16.38abc	17.54abcd	20.77de	20.02cde	19.44
712	(800)		15.29ab	22.42e	21.08de	19.60
1424	(1600)		16.72abc	17.80abcd	22.45e	18.99
Average**			16.34	19.73	20.58	18.88

CV=11.2%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability by "F" test.

TABLE 74. Corn Seedling Weight. Milton, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		g - dry matter				
0	(0)	7.16a				
89	(100)	6.78a				
178	(200)	5.58a	13.45c	6.51a	8.88ab	9.61
356	(400)	8.15ab	6.96a	8.00ab	7.80ab	7.59
712	(800)		8.33ab	8.20ab	12.24bc	9.59
1424	(1600)		8.72ab	9.13ab	12.42bc	10.09
Average**			9.36	7.96	10.33	9.22

CV=27.6%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source-rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 75. Number of Corn Plants Emerged at 17 days. Cambridge, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			Number of Plants Emerged			
0	(0)	45bcd				
89	(100)	43abcd				
178	(200)	46bcd	39ab	42abcd	46bcd	42
356	(400)	41abc	49d	43abcd	46bcd	46
712	(800)		41abc	46bcd	48cd	45
1424	(1600)		37a	44abcd	46bcd	42
Average**			42	44	47	44

CV=8.9%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.05 probability by "F" test.

TABLE 76. Corn Plants Silked at 73 days. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
			Plants silked - % of total			
0	(0)	15.9abcd				
89	(100)	5.3a				
178	(200)	11.5abc	6.9ab	38.6e	31.7de	25.7
356	(400)	10.5abc	7.0ab	32.5de	29.8de	23.1
712	(800)		27.4cde	40.9ef	60.8g	43.0
1424	(1600)		23.7bcde	17.5abcd	55.1fg	32.1
Average**			16.3	32.4	44.4	31.0

CV=36.1%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge, rates of sludge and source-rate interactions are significantly different at 0.01 probability by "F" test.

TABLE 77. Corn Grain Yield, 15% moisture. Elora, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
		lb/ac (kg/ha)			
0 (0)	4368a (4892)				
89 (100)	5866bc (6570)				
178 (200)	5819bc (6518)	5774b (6467)	6344bcde (7105)	6277bcde (7030)	6132 (6867)
356 (400)	6490cde (7269)	6192bcd (6935)	6422bcde (7193)	6411bcde (7181)	6342 (7103)
712 (800)		6434bcde (7206)	6519cde (7301)	6955e (7790)	6636 (7432)
1424 (1600)		6589de (7380)	6483bcde (7261)	6177bcd (6918)	6416 (7186)
Average		6247 (6997)	6442 (7215)	6455 (7230)	6381 (7147)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 78. Corn Grain Yield, 15% moisture. Cambridge, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			lb/ac (kg/ha)		
0 (0)	3453a (3868)				
89 (100)	3757a (4207)				
178 (200)	3656a (4095)	3459a (3874)	3376a (3781)	3797a (4252)	3544a (3969)
356 (400)	3632a (4067)	3594a (4025)	3349a (3750)	3832a (4292)	3591a (4022)
712 (800)		3927a (4398)	3781a (4234)	3831a (4291)	3846a (4308)
1424 (1600)		3389a (3795)	3760a (4211)	3680a (4122)	3610a (4043)
Average		3592a (4023)	3566a (3994)	3785a (4239)	3648a (4086)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

TABLE 79. Corn Grain Yield, 15% moisture. Milton, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
			lb/ac (kg/ha)		
0 (0)	1411ab (1580)				
89 (100)	1281a (1435)				
178 (200)	1553abc (1739)	2994dc (3353)	1441abc (1613)	2069abcd (2317)	2168 (2428)
356 (400)	2101abcd (2353)	2220abcd (2486)	1895abcd (2122)	1692abcd (1895)	1936 (2168)
712 (800)		2355abcd (2637)	2794bcde (3129)	2833cde (3173)	2661 (2980)
1424 (1600)		2974de (3331)	1787abcd (2001)	3780e (4234)	2847 (3189)
Average		2636 (2952)	1979 (2216)	2594 (2905)	2403) (2691)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 80. Corn Stover Yield. Elora, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			dry matter - lb/ac (kg/ha)		
0 (0)	3296ab (3691)				
89 (100)	3657ab (4096)				
178 (200)	3810ab (4268)	3218a (3604)	4178b (4680)	3543ab (3968)	3646 (4084)
356 (400)	3385ab (3791)	3375ab (3780)	3620ab (4055)	3355ab (3758)	3450 (3864)
712 (800)		3073a (3442)	3595ab (4026)	3412ab (3822)	3360 (3763)
1424 (1600)		3602ab (4034)	3430ab (3841)	3531ab (3955)	3521 (3943)
Average		3317 (3715)	3706 (4150)	3460 (3876)	3494 (3914)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

TABLE 81. Corn Stover Yield. Cambridge, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
	Dry matter - lb/ac (kg/ha)				
0 (0)	1943ab (2176)				
89 (100)	1927ab (2159)				
178 (200)	1660ab (1860)	2000ab (2240)	1857ab (2080)	1889ab (2115)	1915 (2145)
356 (400)	1601ab (1793)	1429a (1601)	2131b (2387)	1820ab (2038)	1793 (2009)
712 (800)		1804ab (2021)	2054b (2300)	1656ab (1854)	1838 (2058)
1424 (1600)		1907ab (2136)	1916ab (2146)	1847ab (2069)	1890 (2117)
Average		1785 (1999)	1990 (2228)	1803 (2019)	1859 (2082)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

TABLE 82. Corn Stover Yield. Milton, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		Dry matter - lb/ac (kg/ha)			
0 (0)	927a (1038)				
89 (100)	1060ab (1187)				
178 (200)	965a (1080)	1430abc (1601)	1094ab (1226)	1507abc (1688)	1344 (1505)
356 (400)	1286abc (1440)	1221ab (1368)	1509abc (1691)	1194ab (1337)	1308 (1465)
712 (800)		1268abc (1420)	1534abc (1719)	1497abc (1676)	1433 (1605)
1424 (1600		1601bc (1793)	1406abc (1574)	1833c (2053)	1613 (1807)
Average		1380 (1546)	1386 (1552)	1507 (1689)	1425 (1596)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

TABLE 83. Percentage of Corn Plants Lodged. Milton, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
			Lodged %		
0 (0)	21ab				
89 (100)	22ab				
178 (200)	18a	46de	21ab	29abcd	32
356 (400)	23abc	24abc	26abc	25abc	25
712 (800)		34abcde	41cde	39bcde	38
1424 (1600)		48e	26abc	30abcd	34
Average**		38	29	31	32

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Sludge source, rate, and the source-rate interaction are significantly different at 0.05 probability by "F" test.

TABLE 84. pH in Soil Water Paste of Surface Soil (0-6 in). Elora Corn, Fall, 1973.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
0	(0)	7.1def				
89	(100)	7.1def				
178	(200)	6.9abc	7.3f	7.0bcd	7.1cde	7.1
356	(400)	6.7a	7.3ef	7.1cde	7.0bcd	7.1
712	(800)		7.3f	7.2def	6.8ab	7.1
1424	(1600)		7.3f	7.0cd	6.8ab	7.1
Average**			7.3	7.1	6.9	7.1

CV=1.6 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability and source - rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 85. pH in Soil Water Paste of Surface Soil (0-6 in), Cambridge, Fall 1973.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
0	(0)	7.5abcd				
89	(100)	7.3ab				
178	(200)	7.3ab	7.6abcd	7.6abcd	7.4abcd	7.5
356	(400)	7.2a	7.7cd	7.5abcd	7.3abc	7.5
712	(800)		7.7d	7.4abcd	7.4abcd	7.5
1424	(1600)		7.6bcd	7.5abcd	7.3ab	7.5
Average**			7.7	7.5	7.4	7.5

CV=2.6 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability by "F" test.

TABLE 86. pH in Soil Water Paste of Surface Soil (0-6 in.). Milton, Fall 1973.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
0	(0)	6.5a				
89	(100)	6.5a				
178	(200)	6.3a	6.9bc	6.6ab	6.6ab	6.7
356	(400)	5.7a	7.0c	6.5a	6.4a	6.6
712	(800)		7.2c	6.3a	6.4a	6.6
1424	(1600)		7.2c	6.3a	6.2a	6.6
Average**			7.1	6.4	6.4	6.6

CV=3.3 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability by "F" test.

TABLE 87. Nitrogen Concentration in Corn Seedlings. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% - N		
0	(0)	4.2 c				
89	(100)	3.6 a				
178	(200)	4.2 c	3.8 abc	4.2 c	4.1 bc	4.0
356	(400)	3.7 ab	3.8 abc	4.1 bc	4.0 abc	4.0
712	(800)		3.9 abc	4.1 bc	4.0 bc	4.0
1424	(1600)		4.0 abc	4.1 bc	4.2 bc	4.1
Average**			3.9	4.1	4.0	4.0

C.V. = 5.8%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significant at 0.05 probability by "F" test.

TABLE 88. Nitrogen Concentration in Corn Seedlings. Cambridge, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				% - N		
0	(0)	3.4 a				
89	(100)	4.1 bcde				
178	(200)	4.5 de	3.7 ab	4.0 bc	4.2 bcde	4.0
356	(400)	4.2 cde	3.9 bc	4.2 bcde	4.4 cde	4.1
712	(800)		4.1 bcd	4.3 cde	4.3 cde	4.2
1424	(1600)		4.5 de	4.3 cde	4.6 e	4.5
Average**			4.1	4.2	4.3	4.2

C.V. = 5.8%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significantly different at 0.05 probability and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 89. Concentrations of Various Constituents in Corn Grain at Different Levels of Nitrogen Application. Average Concentration for the Three Sludges Presented, 1974.

		Rates of Nitrogen lb/ac (kg/ha)						
	Sources of	0	89	178	356	712	1424	
Constituent	Nitrogen	(0)	(100)	(200)	(400)	(800)	(1600)	Average
N (%)	NH_4NO_3**	1.0	1.4	1.6	1.5			1.4
Elora	Sludge**			1.4	1.5	1.5	1.6	1.5
N (%)	NH_4NO_3**	1.6	1.7	1.9	1.5			1.7
Cambridge	Sludge			1.8	1.9	1.8	1.9	1.8
K (%)	NH_4NO_3	0.50	0.48	0.49	0.51			0.50
Elora	Sludge*			0.47	0.45	0.50	0.52	0.49
Fe (µg/g)	NH_4NO_3	21	25	22	24			23
Elora	Sludge**			29	23	23	25	25
Zn (µg/g)	NH_4NO_3	29	27	33	31			30
Cambridge	Sludge*			31	30	33	35	32

* Effect of nitrogen rates significant at 0.05 probability by "F" test.

** Effect of nitrogen rates significant at 0.01 probability by "F" test.

TABLE 90. Nitrogen Concentration in Corn Stover. Milton, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				% - N		
0	(0)	1.28ab				
89	(100)	1.43bcd				
178	(200)	1.55cdef	1.55cdef	1.20a	1.53cde	1.43
356	(400)	1.70ef	1.45bcd	1.38abc	1.50bcde	1.44
712	(800)		1.63def	1.50bcde	1.55cdef	1.56
1424	(1600)		1.60cdef	1.77f	1.70ef	1.63
Average**			1.56	1.46	1.53	1.52

CV= 7.7%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge and source-rate interaction are significantly different at 0.01 probability by "F" test.

TABLE 91. Concentrations of Various Constituents in Corn Stover at Different Levels of Nitrogen Application. Average Concentrations for the Three Sludges Presented, 1974.

Constituent	Source of Nitrogen	Rate of Nitrogen lb/ac (kg/ha)						
		0 (0)	89 (100)	179 (200)	356 (400)	712 (800)	1424 (1600)	Average
N (%)	NH_4NO_3	1.6	1.1	1.1	1.2			1.3
Elora	Sludge			1.1	1.1	1.1	1.2	1.1
N (%)	NH_4NO_3**	0.7	0.8	0.9	1.1			0.9
Cambridge	Sludge			1.1	1.1	1.0	1.1	1.0
N (%)	NH_4NO_3	0.7	0.8	1.0	1.2			.9
Milton	Sludge**			0.8	0.9	1.0	1.1	.9
K (%)	NH_4NO_3	1.0	1.0	1.2	1.1			1.1
Cambridge	Sludge*			1.0	1.1	1.1	1.2	1.1
Ca (%)	NH_4NO_3*	.51	.49	.53	.62			.54
Cambridge	Sludge**			.51	.54	.63	.67	.59
NO_3 (%)	NH_4NO_3**	.00	.03	.05	.10			.04
Elora	Sludge**			.03	.06	.08	.12	.07
NO_3 (%)	NH_4NO_3*	.04	.04	.11	.15			.09
Cambridge	Sludge*			.07	.11	.13	.13	.11
Al (µg/g)	NH_4NO_3	980	1100	1153	1080			1050
Milton	Sludge**			1260	1050	760	810	970
Mn (µg/g)	NH_4NO_3	60	61	54	74			62
Milton	Sludge*			67	61	48	57	58
Cu (µg/g)	NH_4NO_3**	2	3	3	6			4
Milton	Sludge**			4	4	5	6	5
Ni (µg/g)	NH_4NO_3	1.8	2.3	2.5	2.0			2.2
Milton	Sludge**			2.7	2.3	1.7	1.8	2.1

* Effect of nitrogen rates significant at 0.05 probability by "F" test.

** Effect of nitrogen rates significant at 0.01 probability by "F" test.

TABLE 92. Nitrate Nitrogen Concentration in Corn Stover. Milton, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		% - NO_3 N				
0	(0)	0.00a				
89	(100)	0.01a				
178	(200)	0.02a	0.05ab	0.02a	0.03ab	0.03
356	(400)	0.06abc	0.02a	0.02a	0.03ab	0.02
712	(800)		0.01a	0.01a	0.11c	0.04
1424	(1600)		0.06abc	0.04ab	0.08bc	0.06
Average**			0.03	0.02	0.06	0.04

CV=86.1%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability by "F" test.

TABLE 93: Sodium Bicarbonate Extractable Phosphorus in Surface Soil (0-6 in). Elora Corn, Fall, 1973.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(µg P/g)		
0	(0)	8a				
89	(100)	7a				
178	(200)	7a	22a	10a	7a	13
356	(400)	10a	7a	17a	12a	12
712	(800)		82b	20a	20a	41
1424	(1600)		18a	23a	14a	19
Average**			33	18	13	21

CV=92 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.05 probability and rates of sludge and the source rate interaction are significant at 0.01 probability by "F" test.

TABLE 94. Sodium Bicarbonate Extractable Phosphorus in Surface Soil (0-6 in). Cambridge, Fall, 1973.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
					(µg P/g)	
0	(0)	75abc				
89	(100)	70abc				
178	(200)	68ab	69ab	75abc	74abc	73
356	(400)	83abcd	113e	92bcde	61a	89
712	(800)		108de	98cde	88abcde	98
1424	(1600)		117e	64ab	81abcd	87
Average**			102	82	76	87

CV=18%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source of sludge and the source - rate interaction are significant at 0.01 probability and rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 95. Sodium Bicarbonate Extractable Phosphorus in Surface Soil (0-6 in). Milton, Fall, 1973*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
				(µg P/g)		
0	(0)	36a				
89	(100)	39ab				
178	(200)	46abcd	58bcde	46abcd	47abcd	50
356	(400)	35a	64de	46abcd	43abc	51
712	(800)		90f	40ab	61cde	63
1424	(1600)		93f	37a	67e	66
Average**			76	42	55	58

CV=20%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source of sludges and rate of sludge and the source - rate interaction are significantly different at 0.01 probability by "F" test.

TABLE 96. Phosphorus Concentration in Corn Seedlings. Elora, 1974.*

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% - P		
0	(0)	0.39 de				
89	(100)	0.32 ab				
178	(200)	0.37 cde	0.33 abc	0.39 e	0.37	0.36
356	(400)	0.32 ab	0.32 ab	0.37 cde	0.33	0.34
712	(800)		0.34 abc	0.37 cde	0.34	0.35
1424	(1600)		0.31 a	0.32	0.36	0.33
Average**			0.33	0.36	0.35	0.35

C.V. = 7.5%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significantly different at 0.01 probability by "F" test.

TABLE 97. Phosphorus Concentration in Corn Seedlings. Cambridge, 1974.*

Nitrogen Source lb/ac (kg/ha)		Nitrogen Source			
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
			% - P		
0 (0)	0.39 abc				
89 (100)	0.40 abc				
178 (200)	0.40 abcd	0.37 a	0.38 ab	0.40 abcd	0.38
356 (400)	0.38 ab	0.40 abcd	0.39 abc	0.41 bcd	0.40
712 (800)		0.42 bcd	0.40 abc	0.43 cd	0.42
1424 (1600)		0.43 cd	0.41 bcd	0.44 d	0.43
Average**		0.41	0.40	0.42	0.41

C.V. = 5.8%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significantly different at 0.05 probability and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 98. Phosphorus Concentration in Corn Seedlings. Milton, 1974.*

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source Ammonium Nitrate	 Calcium Sludge	 Aluminum Sludge	 Iron Sludge	 Sludge Average**
			% - P		
0 (0)	0.32 abc				
89 (100)	0.30 ab				
178 (200)	0.30 ab	0.34 abc	0.39 c	0.30 ab	0.34
356 (400)	0.28 a	0.33 abc	0.35 bc	0.35 bc	0.34
712 (800)		0.29 ab	0.31 ab	0.31 ab	0.30
1424 (1600)		0.29 ab	0.33 abc	0.29 ab	0.31
Average**		0.31	0.35	0.31	0.32

C.V. = 10.7%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge and rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 99. Phosphorus Concentration in Corn Grain. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
			P - %			
0	(0)	0.26ab				
89	(100)	0.25ab				
178	(200)	0.26abc	0.29abcd	0.24a	0.28abcd	0.27
356	(400)	0.29abcd	0.27abcd	0.25ab	0.26ab	0.26
712	(800)		0.32d	0.28abcd	0.30bcd	0.30
1424	(1600)		0.31cd	0.28abcd	0.27abcd	0.29
Average**			0.30	0.27	0.28	0.28

CV=8.8%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.05 probability and rates of sludge are significant at 0.01 probability by "F" test.

TABLE 100. Potassium Concentration in Corn Seedlings. Elora, 1974.*

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				% - K		
0	(0)	2.5 ab				
89	(100)	2.2 a				
178	(200)	2.5 ab	2.1 a	2.6 ab	2.1 a	2.3
356	(400)	2.2 a	2.5 ab	2.6 ab	2.6 ab	2.5
712	(800)		2.5 ab	2.8 bc	3.0 c	2.8
1424	(1600)		2.9 bc	3.3 c	3.3 c	3.2
Average**			2.5	2.8	2.8	2.7

C.V. = 11.7%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significantly different at 0.05 probability and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 101. Potassium Concentration in Corn Seedlings. Cambridge, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% - K		
0	(0)	4.2 abc				
89	(100)	4.2 abc				
178	(200)	3.9 abc	3.4 a	3.9 abc	4.2 abc	3.8
356	(400)	3.6 abc	3.9 abc	4.0 abc	3.7 abc	3.9
712	(800)		3.5 ab	3.9 abc	3.8 abc	3.7
1424	(1600)		3.7 abc	4.3 bc	4.4 c	4.1
Average**			3.6	4.0	4.0	3.9

C.V. = 10.4%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significantly different at 0.05 probability by "F" test.

TABLE 102. Potassium Concentration in Corn Seedlings. Milton, 1974.*

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% - K		
0	(0)	3.0 ab				
89	(100)	3.4 ab				
178	(200)	3.2 ab	3.2 ab	3.1 ab	3.5 ab	3.3
356	(400)	3.4 ab	3.1 ab	3.4 ab	3.0 ab	3.2
712	(800)		2.9 a	3.5 ab	3.6 b	3.3
1424	(1600)		3.1 ab	3.5 ab	3.3 ab	3.3
Average**			3.1	3.4	3.3	3.3

C.V. = 9.8%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significantly different at 0.05 probability by "F" test.

TABLE 103. Potassium Concentration in Corn Stover. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				% - K		
0	(0)	0.72ab				
89	(100)	0.79ab				
178	(200)	0.64a	0.62a	0.66a	0.81abc	0.69
356	(400)	0.86abc	0.66ab	0.77ab	0.78ab	0.74
712	(800)		0.68ab	0.80abc	0.85abcd	0.78
1424	(1600)		0.95abc	1.08cd	1.12d	1.05
Average**			0.73	0.83	0.89	0.82

CV=18.4%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.05 probability and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 104. Potassium Concentration in Corn Stover. Milton, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
		% - K				
0	(0)	0.55a				
89	(100)	0.56a				
178	(200)	0.59ab	0.72abc	0.55a	0.76bc	0.68
356	(400)	0.63abc	0.55a	0.61ab	0.61ab	0.59
712	(800)		0.53a	0.71abc	0.69abc	0.64
1424	(1600)		0.58ab	0.53a	0.81c	0.64
Average**			0.59	0.60	0.72	0.64

CV=15.7%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability and source-rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 105. Calcium Concentration in Corn Seedlings. Milton, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% - Ca		
0	(0)	0.65 ab				
89	(100)	0.68 abc				
178	(200)	0.60 a	0.80 cde	0.68 abc	0.67 abc	0.72
356	(400)	0.74 bcd	0.86 de	0.77 bcd	0.71 abc	0.78
712	(800)		0.90 e	0.77 bcd	0.69 abc	0.79
1424	(1600)		0.85 de	0.64 ab	0.71 abc	0.73
Average**			0.85	0.72	0.70	0.75

C.V. = 8.9%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significantly different at 0.01 probability by "F" test.

TABLE 106. Calcium Concentration in Corn Stover. Milton, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
		% - Ca				
0	(0)	0.30abc				
89	(100)	0.30abcd				
178	(200)	0.28ab	0.38cdefg	0.22a	0.39cdefg	0.33
356	(400)	0.37bcdefg	0.35bcdefg	0.33bcdef	0.32bcde	0.34
712	(800)		0.43fgh	0.39defg	0.41efg	0.41
1424	(1600)		0.51h	0.38cdefg	0.44gh	0.44
Average**			0.42	0.33	0.39	0.38

CV=13.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge and rates of sludge are significantly different at 0.01 probability source-rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 107. Ammonium Acetate Extractable Magnesium in Surface Soil (0-6 in). Elora Corn, Fall, 1973.*

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
			μg/g			
0	(0)	576abc				
89	(100)	549abc				
178	(200)	549abc	501ab	608bc	467a	525
356	(400)	592bc	549abc	592bc	603bc	581
712	(800)		512abc	507ab	629c	549
1424	(1600)		555abc	501ab	603bc	553
Average**			529	552	575	552

CV=11%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source - rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 108. Ammonium Acetate Extractable Magnesium in Surface Soil (0-6 in). Milton, Fall, 1973.*

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg/g		
0	(0)	259bcde				
89	(100)	255abcde				
178	(200)	289e	223abcd	285e	271cde	260
356	(400)	275de	217abc	283e	283e	261
712	(800)		201a	287e	273cde	254
1424	(1600)		207ab	343f	307ef	285
Average**			212	299	283	265

CV=11%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge are significantly different at 0.01 probability by "F" test.

TABLE 109. Magnesium Concentration in Corn Seedlings, Elora, 1974.*

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
		% - Mg				
0	(0)	0.56 cdefg				
89	(100)	0.65 efg				
178	(200)	0.68 g	0.58 cdefg	0.55 bcdef	0.66 fg	0.60
356	(400)	0.60 defg	0.55 bcdef	0.54 bcdef	0.53 abcde	0.54
712	(800)		0.50 abcd	0.46 abc	0.41 a	0.46
1424	(1600)		0.50 abcd	0.41 a	0.43 ab	0.45
Average			0.53	0.49	0.51	0.51

C.V. = 12.1%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 110. Magnesium Concentration in Corn Seedlings. Cambridge, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		% - Mg				
0	(0)	0.29 a				
89	(100)	0.36 abc				
178	(200)	0.42 c	0.41 bc	0.33 abc	0.31 ab	0.35
356	(400)	0.33 abc	0.34 abc	0.31 a	0.38 abc	0.34
712	(800)		0.41 bc	0.36 abc	0.34 abc	0.37
1424	(1600)		0.41 bc	0.33 abc	0.31 ab	0.35
Average**			0.39	0.33	0.34	0.35

C.V. = 14.8%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

**Sources of sludge are significantly different at 0.05 probability by "F" test.

TABLE 111. Magnesium Concentration in Corn Stover. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% - Mg		
0	(0)	0.23a				
89	(100)	0.35bcd				
178	(200)	0.39d	0.37cd	0.36bcd	0.34bcd	0.35
356	(400)	0.36bcd	0.35bcd	0.36bcd	0.34bcd	0.35
712	(800)		0.36bcd	0.37cd	0.32bc	0.35
1424	(1600)		0.33bc	0.33bc	0.31b	0.33
Average**			0.36	0.35	0.33	0.35

CV=7.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Source of sludge are significantly different at 0.05 probability by "F" test.

TABLE 112. Iron Concentration in Corn Stover. Milton, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				Fe -µg/g		
0	(0)	1430ab				
89	(100)	1970b				
178	(200)	1820ab	1680ab	2820c	1480ab	1990
356	(400)	1730ab	1630ab	1630ab	1850ab	1710
712	(800)		1280ab	1270ab	1280ab	1280
1424	(1600)		930a	1780ab	1070ab	1260
Average**			1380	1870	1420	1560

CV=31.4%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge and rates of sludge are significantly different at 0.05 probability by "F" test.

TABLE 113. Concentrations of Chromium, Lead and Mercury in Corn Stover with Different Nitrogen Sources. Field Experiments, 1974.

	Nitrogen Source				
Constituent	NH_4NO_3	Calcium Sludge	Aluminum Sludge	Iron Sludge	Mean
Cr** (µg/g) Cambridge	1.9	1.5	3.8	1.9	2.3
Cr* (µg/g) Milton	1.7	2.3	2.9	1.5	2.2
Pb* (µg/g) Milton	5.5	6.2	5.9	4.6	5.6
Hg* (ng/g) Milton **	16	16	16	23	18

* Effects of nitrogen sources significant at 0.05 probability by "F" test.

**Effects of nitrogen sources significant at 0.01 probability by "F" test.

TABLE 114. Concentration of Mercury in Corn Grain with Different Nitrogen Sources. Field Experiments, 1974.

	Nitrogen Source				
Constituent	NH_4NO_3	Calcium Sludge	Aluminum Sludge	Iron Sludge	Mean
Hg* (ng/g) Milton **	11	16	12	9	12

* Effects of nitrogen sources significant at 0.05 probability by "F" test.

** Hg levels reported are in mg/g (10^{-9} g/g).

TABLE 115. Nickel Concentration in Corn Stover. Elora, 1974.*

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				Ni -µg/g		
0	(0)	1.17a				
89	(100)	0.86a				
178	(200)	1.08a	0.96a	1.67a	1.92a	1.51
356	(400)	1.25a	1.03a	1.67a	1.46a	1.38
712	(800)		1.58a	1.33a	1.25a	1.39
1424	(1600)		1.50a	5.33b	1.92a	2.92
Average**			1.27	2.50	1.64	1.80

CV=63.6%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge and sludge-rate interactions are significantly different at 0.05 probability and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 116. Zinc Concentration in Corn Stover. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				Zn -µg/g		
0	(0)	16ab				
89	(100)	15a				
178	(200)	16a	23abcd	19abc	23abcd	22
356	(400)	22abcd	22abcd	27bcde	28cdef	26
712	(800)		38fg	31def	42g	37
1424	(1600)		36efg	54h	69h	53
Average**			30	33	40	34

CV=20%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge, rates of sludge and the source-rate interactions are all significantly different at 0.01 probability by "F" test.

TABLE 119. Zinc Concentration in Corn Stover. Cambridge, 1974

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				µg Zn/g		
0	(0)	59abc				
89	(100)	47ab				
178	(200)	70abcd	44a	58abc	64abc	56
356	(400)	80abcd	47ab	88abcde	61abcd	65
712	(800)		95bcdef	100cdef	108defg	101
1424	(1600)		151g	133efg	135fg	140
Average			84	95	92	90

CV=29.8%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 118. Zinc Concentration in Corn Stover. Milton, 1974.*

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				µg Zn/g		
0	(0)	24abcd				
89	(100)	23abcd				
178	(200)	20abc	16a	30d	21abc	23
356	(400)	23abcd	18ab	26bcd	28cd	24
712	(800)		21abcd	24abcd	22abcd	22
1424	(1600)		23abcd	43e	29cd	32
Average**			20	31	25	25

CV=19%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge and rates of sludge are significantly different at 0.01 probability and source-rate interactions are significantly different at 0.05 probability by "F" test.

TABLE 119. Zinc Concentration in Corn Grain. Elora, 1974.*

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average**
				Zn µg/g		
0	(0)	21abc				
89	(100)	19a				
178	(200)	21abc	22abcd	20ab	25bcde	22
356	(400)	20ab	20abc	24abcd	25bcde	23
712	(800)		25cde	24bcd	27de	26
1424	(1600)		24bcd	27de	30e	27
Average**			23	24	27	24

CV=11.8%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability.

** Sources of sludge and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 120. Concentration of Various Constituents in Corn Grain Where a Normal Rate [89 lb/ac (100 kg/ha)] of Nitrogen Was Applied as NH_4NO_3. Field Experiment, 1974.

Constituent	Site Elora	 Cambridge	 Milton	Average
N (%)	1.4	1.70	1.40	
NO_3 (%)				
P (%)	0.25	0.34	0.24	
K (%)	0.48	0.49	0.54	
Ca (%)	0.06	0.06	0.04	
Mg (%)	0.12	0.15	0.12	
Na				
Al (μg/g)	5.20	4.30	4.30	
Fe (μg/g)	25	23	20	
Mn (μg/g)	2.70	5.70	5.30	
B (μg/g)				
Cd (μg/g)	0.13	0.17	0.15	
Cu (μg/g)	2.00	4.70	1.30	
Cr (μg/g)	0.50	0.30	0.37	
Ni (μg/g)	0.42	0.17	0.33	
Pb (μg/g)	0.93	0.53	0.47	
Zn (μg/g)	19	27	21	
Hg (ng/g)*	12	13	22	

* 10^{-9} g/g units

TABLE 121. Concentration of Various Constituents in Corn Stover Where a Normal Rate [89 lb/ac (100 kg/ha)] of Nitrogen Was Applied as NH_4NO_3. Field Experiment, 1974.

Constituent	Site Elora	Cambridge	Milton	Average
N (%)	1.05	0.75	0.82	
NO_3 (%)	.03	0.04	0.01	
P (%)	0.10	0.11	0.10	
K (%)	0.79	1.04	0.56	
Ca (%)	0.54	0.49	0.30	
Mg (%)	0.35	0.23	0.24	
Na				
Al (μg/g)	180	770	1100	
Fe (μg/g)	390	1007	1970	
Mn (μg/g)	49	86	61	
B (μg/g)	6.0	5.3	5.7	
Cd (μg/g)	0.28	0.35	0.09	
Cu (μg/g)	6.7	8.3	3.3	
Cr (μg/g)	0.83	1.93	1.67	
Ni (μg/g)	0.86	1.58	2.27	
Pb (μg/g)	4.7	10.30	6.3	
Zn (μg/g)	15	47	23	
Hg (ng/g)*	52	24	14	

* 10^{-9} g/g units.

5. NITROGEN

5.1 Objectives

The objectives of the research with sludge nitrogen were to determine what factors are involved in the conversion of nitrogen applied in sludge to NH_4^+ and NO_3^-, and to determine the movement of NO_3^- through the soil profile.

5.2 Materials and Methods

5.2.1 Soil profile sampling for NO_3^-, NH_4^+ and pH

Three replicates of plots receiving 0, 356 (400) and 712 (800) lb N/ac (kg/ha) of iron treated sludge were sampled in each of the three corn experiments and the grass experiment in June, October and November, 1974. It should be noted that in April or early May the plots having received 0, 712 (800) and 1424 (1600) lb N/ac (kg N/ha) of iron sludge the previous year were sampled. The change in treatments sampled resulted from a conclusion that the rates of 0, 356 (400) and 712 (800) lb N/ac (kg/ha) covered a range more likely to be covered with the guidelines of sludge application which are being evolved. The following depths or layers were sampled: 0-6 (0-15), 6-12 (15-30), 12-18 (30-45), 18-24 (45-60) and 24-36 (60-90) inches (cm). NO_3^-, NH_4^+ and pH determinations were made using the methods reported in Volume II of this study for FY 73/74.

5.2.2 Surface soil sampling for NO_3^-, NH_4^+ and pH

At the end of June, the surface 0-6 in (0-15 cm) of soil on selected plots other than those sampled from the profile were sampled. The plots sampled were the three replications of the 89 (100) and 356 (400) lb N/ac (kg N/ha) with the ammonium nitrate treatment, and 356 (400) and 712 (800) lb N/ac (kg N/ha) with the calcium and aluminum sludge treatments. Data from similar treatments with the iron sludge from the 0-6 in (0-15) layer of the profile sampling were included for comparisons. NO_3^-, NH_4^+, and pH were determined by methods previously indicated in Volume II of this study.

5.2.3 Soil solution study

Soil solution samplers with ceramic tips were inserted in the soil to a depth of three feet in 2.5 percent slope plots which received 100 kg N/ha as NH_4NO_3 or 800 kg N/ha as sludge in the runoff experiment. In addition, samplers were similarly inserted in plots of the corn experiment at Elora which received the following treatments: 100, 200 and 400 kg N/ha as NH_4NO_3 and 200, 400 and 800 kg N/ha of iron sludge. In addition, samplers were inserted only to the 1.5 foot depth in plots of this experiment which had received 1600 kg N/ha as Ca-, Al- and Fe-treated sludges. These were inserted to this shallower depth with the objective of determining the presence of heavy metals in the soil solution.

Two samplers were inserted in each plot with the appropriate treatment (two replications) of the runoff experiment whereas one sampler was inserted in each plot of the appropriate treatment (three replications) in the corn experiment at Elora. The samplers were inserted during July and August. Samples of subsoil water were taken beginning in September and on a biweekly basis beginning October 21, 1974 for NO_3^- analysis.

5.2.4 Laboratory studies

The laboratory experiment (Experiment 1) reported on at the Sludge Handling and Disposal Seminar, Toronto, Ontario, September 18-19, 1974 was continued and finally terminated January 2, 1974, after 53 weeks. The methods and materials for this experiment were outlined in Volume II of this study for FY 73/74.

A second experiment (Experiment 2) of similar design to Experiment 1 was begun to compare nitrification rates and patterns of different sludges mixed with soil. A major reason for this experiment was to determine whether the aluminum sulphate treatment may be responsible for retarding the nitrification process. Sludges from Tilsonburg, Kitchener, Guelph, Point Edward (1973) which were treated with aluminum sulphate are being compared with sludges from North Toronto and Point Edward (1974) which were treated with ferric chloride (Table 122). As in Experiment 1, sludge was mixed with a silt loam so as to provide 12,000 µg N in a mixture of 15 g soil plus 15 g medium quartz sand. The treated soil was placed in a Buchner funnel, incubated at approximately 0.3 bar moisture and 25°C and leached weekly. The leachates were analysed for NO_3^--N. The experiment is currently in its 17th week and will be continued.

A third experiment (Experiment 3) has just been set up to study the rate of decomposition of the "organic N" component of sludge N. Five sludges varying in N content and chemical treatment (Table 123) were chosen for this study. The soluble and exchangeable NH_4^+ fractions were removed from each of the sludges by centrifugation and two extractions with water and then two extractions with 2N KCl followed by two washings with water to remove any KCl present. Water was then added to reconstitute the residual sludge to approximate the consistency of the original sludges. Each reconstituted sludge containing only organic N was then mixed with a soil/sand mixture (15 g soil + 15 g medium quartz sand) and placed in a Buchner funnel. (The quantity of sludge used was such that 12,000 μg N was added per 15 g soil.) The treated soil/sand mixture was then immediately leached with 125 ml of H_2O and incubated at 0.3 bar moisture tension. Leachates were collected weekly and analysed for NO_3^-, NH_4^+ and total N. Each treatment was replicated three times.

5.2.5 Greenhouse study

The soil in pots of the Greenhouse Experiment described in section 6 was sampled after the first harvest of ryegrass and analysed for water soluble NO_3^- and exchangeable NH_4^+. Possible subsequent samplings for this purpose were not undertaken because of a special treatment applied to these soils to remove excessive quantities of salts.

5.3 Results and Discussion

5.3.1 Soil profile samplings for NO_3^-, NH_4^+ and pH

5.3.1.1 NO_3^- concentrations in soil profiles. The data in Tables 124, 125, 126 and 127 show that there was a considerable residual quantity of NO_3^- in the profile following sludge application in 1973, particularly on the silt loam site, in late April or early May (Table 125). The quantity of NO_3^- significantly decreased with depth only on the clay loam site (Table 126) although appreciable decreases with depth also occurred in the other soils (Tables 124 and 125). Samples from two replications for the April 19, 1974 sampling of the grass experiment were lost; therefore, analysis of variance of the remaining data from one replication was impossible (Table 127). The NO_3^- present in the profiles at this early sampling may have been due to incomplete leaching of the NO_3^- present the previous fall or nitrification of residual sludge N during the period following soil thawing.

The NO_3^--N concentrations increased with increasing sludge N application at the June 27, October 7 and November 15 sampling of the sandy loam profile under corn (Table 128). The concentrations in different layers were significantly different at all three sampling dates. It was apparent that NO_3^- had moved down below the 0-6 (0-15) in (cm) layer by the October 7 and November 15 samplings. However, the movement from October 7 to November 15 was only approximately 6 in (15 cm) because of the relatively small amount of rainfall.

The concentrations of NO_3^--N in the silt loam profile on June 24 and October 1 were greater (Table 129) than that in the sandy loam profile (Table 128). The movement of NO_3^- down the profile on November 13 was not as great as that for the sandy loam profile at approximately the same time. The significant depth x rate interaction effect for the October 1 sampling indicates that the concentration with depth depended on the rate of sludge N application.

There was no indication of NO_3^- movement down the clay loam profile (Table 130) probably because of the relatively low rainfall during the late summer and fall months. There was no apparent evidence of NO_3^- disappearance through denitrification in this profile. The significant depth x rate interaction for the June 28 and November 11 samplings indicate that the distribution of NO_3^--N concentration down the profile depended on the rate of sludge N application. This was most likely due to the increasingly high NO_3^--N concentration in the 0-6 (0-15) in (cm) layer with increasing sludge N application but not in the lower layers.

The concentration of NO_3^--N was much lower in the soil profile under grass than in the profiles under the corn plots (Table 131). This may be due to decreased nitrification of NH_4^+ or greater absorption of

NH_4^+ and NO_3^- by the grass crop. A significant depth x rate interaction for all three samplings probably occurred for the same reason suggested in the previous paragraph.

5.3.1.2 NH_4^+ concentrations in soil profiles. The application of sludge in 1973 resulted in some residual NH_4^+ present especially in the upper part of the profile (Tables 124, 125, 126 and 127). However, the NH_4^+-N concentration was relatively low and not substantially different with sludge treatments, although significant effects were obtained (Tables 124, 125 and 126).

Although the NH_4^+-N concentration differed with depth at the June 27, October 7 and November 15 samplings in the sandy loam profile, only at the June 27 sampling did sludge applications have a significant effect (Table 132). Similar results were obtained for the June 24, October 1 and November 13 samplings of the silt loam profile under corn (Table 133).

There was a relatively large increase in NH_4^+-N concentration with increasing sludge applied with the June 28 sampling at the clay loam site (Table 134). Since the increase occurred mainly in the 0-6 in (0-15 cm) layer, the depth x rate interaction effect was highly significant. Similarly, the depth x rate interaction effect was significant at the October 4 sampling although the concentration was much lower than that at the June 28 sampling.

The NH_4^+-N concentrations in the silt loam profile under grass were similar to those for corn at the June 18 and September 30 samplings (Table 135). However, the NH_4^+-N concentration under grass was relatively greater than under corn at the November 13 sampling.

5.3.1.3 pH in soil profiles. Sludge treatment had no effect on the pH of the soil at the earliest sampling in 1974 (Tables 124, 125, 126 and 127). The significant depth x rate interactions at the silt loam site (Table 125) appeared to be due to slightly different trends in pH change down the soil profile with each treatment. The changes were small, however.

The soil pH in the sandy loam profile increased down the profile, a natural phenomenon (Table 136). However, the rate of sludge application appeared to have a small effect on soil pH at the June 27 and November 15 samplings. It appeared that the intermediate application (400 kg sludge N/ha) decreased pH to the greatest extent.

Sludge appeared to slightly decrease pH at all three samplings in the silt loam profile under corn (Table 137). This change appeared to occur only in the upper 30 and 45 cm of the profile as evidenced by the significant depth x rate interaction effect at the October 1 sampling. It thus appears that slight pH changes will occur after two applications on coarser textured soils.

Sludge applications had no significant effect on soil pH in the clay loam profile at any of the sampling dates (Table 138). The significant increase with depth is a natural phenomenon. Similarly, sludge applications had no influence on the pH of the silt loam profile under grass (Table 139). The significant depth x rate interaction effect with the September 30 sample appears to be of little practical importance.

5.3.2 Surface soil sampling for NO_3^-, NH_4^+ and pH

5.3.2.1 NO_3^--N concentrations in surface soils. The higher rate (356 lb N/ac) of N as ammonium nitrate significantly increased the NO_3^--N concentrations in the soil at all three sites where corn was grown (Tables 141, 142, 143 and 144). However, the concentration of NO_3^--N with the higher rate of NH_4NO_3 was lower at the sandy loam site than at the other sites.

The quantity of NO_3^--N produced by each of the sludges at each of the sites may be related to the amount of NH_4^+-N applied in the sludges (Table 140). Thus it appears that the aluminum sludge invariably contained more NH_4^+-N than the iron sludge which, in turn, contained more NH_4^+-N than the calcium sludge. The NH_4^+-N concentration appeared to influence the NO_3^--N concentration at the silt loam and clay loam sites (Tables 142 and 143) but not at the sandy loam site (Table 141).

The NO_3^--N concentrations were generally much lower in the surface soil at the grass site (Table 144) than at the corn sites, possibly due to restricted nitrification. The NH_4NO_3 source of N resulted in NO_3^--N concentrations which were generally not different from those with the sludge N source. (Although considerable NO_3^- was applied in the NH_4NO_3 source, the grass crop may have absorbed most of the NO_3^- by the time of sampling). The relative levels of NO_3^--N with the sludge sources appeared to correspond with the quantity of NH_4^+-N applied in each sludge (Table 140).

5.3.2.2 NH_4^+-N concentrations in surface soils. The NH_4^+-N concentrations were generally lower at the sandy loam site than at the other two sites at which corn was grown (Tables 145, 146 and 147). Except at the silt loam site (Table 146), the higher level of the NH_4NO_3 source did not increase the NH_4^+-N concentration in the surface soils. Generally, the aluminun sludge resulted in the highest NH_4^+-N concentration in the surface soils at the corn sites. The higher content of NH_4^+-N in the iron sludge did not appear to have any consistent influence on soil NH_4^+ concentration relative to the NH_4^+-N content of the calcium sludge.

The NH_4^+-N concentration in the surface soil at the grass site (Table 148) was approximately similar to that found at the corn site on silt loam (Table 146). Although more NH_4^+-N was applied with the iron sludge than with the calcium sludge, the latter source resulted in higher NH_4^+-N concentration in the surface soil. This also occurred with the corn plots on silt loam (Table 146). The reason for this is not readily apparent at this time.

5.3.2.3 pH in surface soils. The pH in the 0-6 in (0-15 cm) layer was significantly higher where calcium sludge was applied (Tables 149, 150, 151 and 152). Where ammonium nitrate was applied, the pH tended to be lower with the higher rate and was significantly lower in the clay loam soil (Table 151). This was probably caused by the acidifying nature of the nitrification process involved in conversion of NH_4^+ to NO_3^- by soil microorganisms. This effect was not so evident with the sludge although the iron sludge at 712 lb N/ac resulted in a significantly lower pH than the 356 lb N/ac treatment on the silt loam site (Table 150).

5.3.3 Soil solution study

Because of the small amounts of rainfall during the late summer and fall months, water samples were not obtained from all of the samplers at each date of sampling.

The NO_3^--N concentration was generally higher with the 800 kg N/ha treatment in the runoff experiment (Table 153). While the NO_3^--N concentration was generally below the accepted level of 10 µg NO_3^--N/ml in the runoff experiment with 100 kg N/ha as NH_4NO_3, the level was much higher in the corn experiment; the reason for this is not apparent. The concentration with the 200 kg N/ha as NH_4NO_3 treatment generally exceeded that for the 100 kg N/ha treatment by a substantial margin.

The NO_3^--N concentration with Fe-sludge in the corn experiment at the 200 kg N/ha treatment was generally lower than that with NH_4NO_3 at 100 kg N/ha (Table 153). The 400 kg N/ha treatment of Fe-sludge generally resulted in NO_3^--N concentrations higher than for the 200 kg N/ha treatment. However, a further increase in Fe-sludge application to 800 kg N/ha generally did not increase the NO_3^--N concentration.

The NO_3^--N concentration with the 1600 kg N/ha level of application of the sludges was increased considerably at the 1.5 foot (45 cm) depth compared with other treatments at the 3 foot (90 cm) depth. There appeared to be less NO_3^- at this depth with the Ca sludge than with the other two sludges.

The Cl^- concentration appeared to be generally dependent on the amount of sludge applied (Table 154). However, there also appears to be some correspondence between the Cl^- concentration and the NO_3^--N concentration (Table 153) for the various treatments, including those with NH_4NO_3 as the N source. The 1600 kg N/ha rates of different sludges resulted in a very high concentration at the 1.5 foot (45 cm) depth.

5.3.4 Laboratory studies

Data from laboratory Experiment 1 for the first 27 weeks were reported at the Sludge Handling and Disposal Seminar, September 18-19, 1974. During the 26 weeks following, NO_3^--N continued to be produced by soil treated with all three sludges (calcium, aluminum and iron treated sludges). The wet or dry pretreatment outlined in Volume II of this study appeared to have little influence on NO_3^- production during the last half of the incubation period. There appeared to be three periods, week 19 to week 26, week 27 to week 40 and week 41 to week 52, during which the rate of nitrification appeared to be different for the sludges as shown in Table 155. The NO_3^--N production was relatively high for the iron and calcium sludge during the 19th to 26th week period. The NO_3^--N production decreased appreciably for the iron sludge during the period of week 27 to week 52, whereas that for the calcium sludge decreased gradually over the same period. NO_3^--N production was relatively high during the period of week 27 to week 40 but then decreased again. At the end of the experiment it was evident that NO_3^--N production from the iron and calcium sludges had far exceeded the quantity of N applied with the sludge in the NH_4^+ form. This suggested that a considerable portion of the organic N fraction in the sludge had mineralized and was converted to the NO_3^- form. At the end of the experiment, the NO_3^--N production approximately equalled the addition of NH_4^+-N in the aluminum sludge. Judging from the relative rates of NO_3^--N production from the soil treated with the three sludges (Table 155), it appeared that the total amount of N converted to the NO_3^- form would be less with the aluminum sludge than with the other two sludges. It thus appears that the high hydrocarbon content of the aluminum sludge (Point Edward, 1973) somehow resulted in a lower recovery of sludge N in the NO_3^- form. Unfortunately, this experiment did not include a check treatment, which meant that the production of NO_3^- by the soil itself could not be estimated. This shortcoming was not repeated in Experiment 2.

Experiment 2 has now been in operation for 17 weeks. The production of NO_3^--N from soil treated with the sludges was greatly different in a manner not related to the chemical treatment (Table 122). Also, the level of NH_4^+-N in the sludge did not appear to have any influence on the NO_3^--N production. It is noteworthy that both Point Edward sludges resulted in much lower NO_3^--N production than did the others. Thus it appears that although the chemical treatment of sewage at the Point Edward treatment plant had been changed there was some characteristic of the sludge which apparently inhibited the nitrification process. NO_3^- appeared during the second week with the North Toronto and Tillsonburg sludges and during the third week with the Guelph and Kitchener sludges. However, NO_3^- appeared first during the sixth week with the Point Edward (1974) sludge and during the ninth week with the Point Edward (1973) sludge. The rate of NO_3^- production was relatively high during the first few weeks for the North Toronto, Tillsonburg, Guelph and Kitchener sludges. The rate has tapered off during recent weeks although it is still considerable. The rate of NO_3^- production has been relatively constant over time for both the Point Edward (1973) and Point Edward (1974) sludges, although much slower for the former.

Only two leachates have been collected and analysed for NO_3^- in Experiment 3. The NO_3^--N concentration data are presented in Table 156. Although there was little apparent mineralization of sludge organic N at week 1, there was substantial mineralization with some of the other sludges by the second week. The highest production occurred with the Kitchener, North Toronto and Guelph sludges. Reasons for this enhanced production are not yet apparent. It is noteworthy that the NO_3^--N production decreased during the second week for the Point Edward sludge. The rate of NO_3^- production was considerably less than that for the untreated soil.

5.3.5 Greenhouse study

5.3.5.1 NO_3^--N concentrations in soil. The significant sludges x sludge N rate interaction (Table 157) suggested that the amount of NO_3^- remaining in the soil after the first harvest depended both on the source and the rate. Generally, the amount of NO_3^--N present depended on the relative proportion of the sludge N which was in the NH_4^+-N form. Also, the NO_3^--N concentration increased with the rate of application. A tentative observation is that the relative concentration of NO_3^--N with the Fergus sludge at the highest rate of application is lower than the others, taking into consideration the proportion of NH_4^+-N applied. The Fergus sludge had a high concentration of Cu. Other differences amongst sludges are not explainable at this time.

5.3.5.2 NH_4^+-N concentrations in soil. As shown in Table 157, all the main effects and interactions were significant (Table 158). The source of the significant interaction effect of sludges and sludge N rates is difficult to discern, except that the amount of NH_4^+-N present may have depended on the rate of each sludge in a different manner. The sludge N rate x pH interaction occurred because the increase of NH_4^+-N with rate was greater at soil pH 5.0 than at soil pH 7.0. This may mean that NH_4^+ was more readily nitrified at pH 7.0 or that the mineralization of sludge "organic" N was more rapid at pH 5.0. The sludges x sludge N rates x pH interaction may be interpreted to mean that the amount of NH_4^+-N present for each sludge depended on the rate and on soil pH. The high NH_4^+-N concentration with the highest application of the Fergus sludge may be due to the high Cu content of this sludge resulting in nitrification inhibition.

5.4 Summary and Conclusions

5.4.1 Soil profile sampling for NO_3^-, NH_4^+ and pH

There was a considerable quantity of residual NO_3^- present in the profile at each site at the first sampling in 1974 before sludge was applied. It cannot be ascertained whether the NO_3^- persisted in the profile over the winter months or was produced after soil thawing in the spring.

The NO_3^--N concentration in the profiles increased substantially following the 1974 application of sludge on plots which had received the same rate of sludge N the previous year. It was apparent that some movement of NO_3^- down the profile occurred but not to the same extent as during the previous year because of lower rainfall. The NO_3^--N concentration was much greater in the silt loam and clay loam profiles than in the sandy loam profile. The reason for this is not apparent since little leaching occurred. There was no apparent loss of NO_3^- in the clay loam profile as in the fall of the previous year when denitrification apparently occurred. As in the previous year the NO_3^--N concentration under grass was much lower than that under corn on the silt loam site.

The NH_4^+-N concentration in the profiles at the various samplings was relatively low and not substantially affected by sludge treatments. This may be due to the relatively rapid conversion of NH_4^+ to NO_3^- when sludge is applied or incorportated into soil.

There appeared to be an effect of sludge application on pH of the uppermost soil layer at the sandy loam and silt loam sites. This was likely due to the acidity resulting during the nitrification process. It may suggest that the buffering capacity of these coarser soils may have been slightly impaired following two sludge applications.

5.4.2 Surface soil sampling for NO_3^-, NH_4^+ and pH

The quantity of NO_3^- produced in the surface soil with the sludge treatments at each site appeared to be related to the quantity of NH_4^+-N applied with the sludge. Thus, the aluminum sludge appeared to produce more NO_3^- than did the other two sludges. This effect was most apparent at the silt loam and clay loam sites.

The pH of the surface soils which received calcium sludge were higher than for the other sludges. Thus, the acidifying effect of the nitrification process may be countered by the lime applied with the calcium sludge.

5.4.3 Soil solution study

Considerable difficulties were encountered in obtaining soil solution samples from each of the ceramic-tipped samplers because of the relatively low rainfall during the late summer, fall and early winter months. In general, however, the NO_3^--N concentration was higher than that normally accepted (10 μg NO_3^--N/ml). Even low rates of NH_4NO_3 or sludge N resulted in high NO_3^--N concentrations. This may be related to the relatively low quantities of rain water. The concentration of Cl^- generally tended to coincide with the NO_3^--N concentration in the samples obtained.

5.4.4 Laboratory studies

In Experiment 1, NO_3^- production continued up to and including the 52nd week at which time the experiment was terminated. The NO_3^- production from the aluminum sludge (Point Edward, 1973) treated soil was much lower than for soil treated with calcium or iron sludge. Thus the apparent disappearance, indicated earlier (Sludge Handling and Disposal Seminar, September 18-19, 1974), of available NH_4^+-N appears to be real. Although no mechanism for this apparent disappearance can be suggested at this time, the possible role of hydrocarbon content cannot be ignored.

In Experiment 2, now in operation for 17 weeks, the production of NO_3^- differed depending on the sludge source but not in a manner which can be related to either the chemical treatment or NH_4^+-N content of the sludges at this time. Some unknown factor appears to be operative in regulating NO_3^- production. It is noteworthy in this respect that the Point Edward (1974) sludge resulted in considerably less NO_3^- production than other sludges, in a manner not dissimilar to that for the Point Edward (1973) sludge but not as pronounced. It should be further noted that the Point Edward (1974) sludge was treated with $FeCl_3$ whereas the Point Edward (1973) sludge was treated with $Al_2(SO_4)_3$.

The few data available for Experiment 3 suggest that the organic N in some sludges may be readily transformed to NO_3^-. However, the Point Edward (1974) sludge appears to have an inhibiting effect on this transformation.

5.4.5 Greenhouse study

The amount of NO_3^- remaining in the soil after the first harvest of ryegrass depended on both the source and rate of sludge applied. Generally, the amount of NO_3^- present depended on the amount of NH_4^+-N applied. Although the concentration of Cu in one sludge may have affected the production of NO_3^-, this cannot be ascertained at this time. The amount of NH_4^+-N present in the soil depended on the amount of sludge applied and, in some instances, apparently on the relative rate of nitrification of the NH_4^+. The increase of NH_4^+-N concentration appeared to be greater at soil pH 5.0 than 7.0. It could not be ascertained whether this was due to increased nitrification at pH 7.0.

TABLE 122. Total Nitrogen and Soluble and Exchangeable NH_4^+ in Six Sludges Used in the Laboratory Studies and NO_3^--N Production During 17 Weeks Incubation With Soil (Experiment 2).

		Sludge N Fractions			
Sludge Source	Treatment	Total N*	Soluble NH_4^+-N	Exchangeable NH_4^+-N*	NO_3^--N Production
		%	(μg/g)	(μg/g)	(μg/g/17 wk)
North Toronto	$FeCl_3$	0.30	913	63	243
Pt. Edward (1973)	$Al_2(SO_4)_3$	0.10	400	25	20
Pt. Edward (1974)	$FeCl_3$	0.31	588	63	80
Kitchener	$Al_2(SO_4)_3$	0.28	1250	84	140
Guelph	$Al_2(SO_4)_3$	0.17	613	38	156
Tilsonburg	$Al_2(SO_4)_3$	0.17	555	61	230

*fluid basis.

TABLE 123. N Composition of Original Sludges, Total Organic N Lost in NH_4^+ Removal Procedure, and Total Organic N Composition of Reconstituted Sludges Used in Laboratory Experiment 3.

(µg Ng)

			Original Composition				Total Org. N removed in Washes	Residual org. N, H_2O added
Sludge Source	Treatment	Date Sampled	Total N	H_2O Sol. NH_4^+-N	Exch. NH_4^+-N	Org. N		
Kitchener (4)	$Al_2(SO_4)_3$	8/5/74	3500	1200	167	2133	428	2650
North Toronto (1)	$FeCl_3$	20/11/74	3000	713	80	2207	387	2430
Point Edward (1)	$FeCl_3$	27/11/74	1800	513	25	1262	257	1515
Newmarket (2)	$Ca(OH)_2$	26/11/74	1700	313	30	1357	219	1850
Guelph	$Al_2(SO_4)_3$	28/11/74	1400	550	35	815	124	1820

TABLE 124. NO_3^--N and Exchangeable NH_4^+-N Concentrations and pH in Sandy Loam Soil Profile (Cambridge; Corn Experiment) in Plots Having Received Different Quantities of Fe-treated Sludge. Sampled April 8-9, 1974.

	Depth	Sludge Rate - lb N/ac (kg N/ha)			Significance of Effect*		
	in (cm)	0	712 (800)	1424(1600)	Depths	Rates	D x R
			(μg NO_3^--N/g)				
NO_3^--N	0- 6 (0-15)	4.8	5.1	7.3	N.S.	0.05	N.S.
	6-12 (15-30)	4.5	3.6	4.7			
	12-18 (30-45)	2.3	2.5	4.7			
	18-24 (45-60)	2.1	2.4	3.8			
	24-36 (60-90)	2.2	2.0	6.9			
			(μg NH_4^+-N/g)				
NH_4^+-N	0- 6 (0-15)	4.0	3.0	6.0	0.01	0.05	N.S.
	6-12 (15-30)	3.4	2.0	3.2			
	12-18 (30-45)	1.2	1.1	2.4			
	18-24 (45-60)	1.5	0.7	1.6			
	24-36 (60-90)	1.0	0.5	0.8			
pH	0- 6 (0-15)	7.8	8.0	7.9	0.01	N.S.	N.S.
	6-12 (15-30)	8.0	8.0	8.0			
	12-18 (30-45)	8.1	8.2	8.1			
	18-24 (45-60)	8.2	8.2	8.3			
	24-36 (60-90)	8.0	8.0	8.0			

* .05 and .01 indicate level of significance, N.S. indicates effect not significant at .05 level of probability.

TABLE 125. NO_3^--N and Exchangeable NH_4^+-N Concentration, and pH in Silt Loam Soil Profile (Elora; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled April 18-19, 1974.

	Depth	Sludge Rate - lb N/ac (kg N/ha)			Significance of Effect*		
	in (cm)	0	712 (800)	1424 (1600)	Depths	Rates	D x R
			(μg NO_3^--N/g)				
NO_3^--N	0- 6 (0-15)	12.7	19.5	20.6	N.S.	.01	N.S.
	6-12 (15-30)	9.4	23.5	22.8			
	12-18 (30-45)	4.6	21.5	30.6			
	18-24 (45-60)	3.4	17.3	21.5			
	24-36 (60-90)	3.0	13.3	14.4			
			(μg NH_4^+-N/g)				
NH_4^+-N	0- 6 (0-15)	1.8	2.0	3.4	.01	.01	N.S.
	6-12 (15-30)	2.0	2.2	5.1			
	12-18 (30-45)	1.6	1.6	3.2			
	18-24 (45-60)	0.2	0.6	1.4			
	24-36 (60-90)	0.2	0.2	0.3			
pH	0- 6 (0-15)	7.2	7.3	7.2	.01	N.S.	.01
	6-12 (15-30)	7.3	7.2	7.3			
	12-18 (30-45)	7.4	7.4	7.3			
	18-24 (45-60)	7.4	7.5	7.5			
	24-36 (60-90)	7.5	7.7	7.6			

* .05 and .01 indicate level of significance, N.S. indicates effect not significant at .05 level of probability.

TABLE 126. NO_3^--N Concentration, NH_4^+-N Concentration and pH in Clay Loam Soil Profile (Milton; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled May 6, 1974.

	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	in	(cm)	0	712(800)	1424(1600)	Depths	Rates	D x R
				(μg NO_3^--N/g)				
NO_3^--N	0- 6	(0-15)	19.1	21.2	22.9	.01	.01	N.S.
	6-12	(15-30)	13.8	14.7	22.2			
	12-18	(30-45)	8.5	13.5	18.7			
	18-24	(45-60)	7.4	13.6	14.3			
	24-36	(60-90)	8.3	12.6	13.3			
				(μg NH_4^+-N/g)				
NH_4^+-N	0- 6	(0-15)	3.9	7.1	7.7	.01	.01	N.S.
	6-12	(15-30)	3.7	4.6	7.3			
	12-18	(30-45)	2.3	3.7	4.2			
	18-24	(45-60)	1.4	3.2	4.0			
	24-36	(60-90)	1.2	2.4	2.7			
pH	0- 6	(0-15)	7.0	7.1	7.1	.01	N.S.	N.S.
	6-12	(15-30)	6.8	7.0	6.8			
	12-18	(30-45)	7.0	7.5	6.6			
	18-24	(45-60)	7.6	7.3	7.1			
	24-36	(60-90)	7.7	7.8	7.8			

* .05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 127. NO_3^--N and NH_4^+-N Concentrations, and pH in Silt Loam Soil Profile (Elora; Bromegrass Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled April 19, 1974.*

	Depth in (cm)	Sludge Rate - lb/ac (kg/ha) 0	 712 (800)	 1424 (1600)
			(μg NO_3^--N/g)	
NO_3^--N	0- 6 (0-15)	7.4	9.0	15.2
	6-12 (15-30)	3.2	5.1	10.9
	12-18 (30-45)	2.2	3.7	11.9
	18-24 (45-60)	1.3	1.2	7.2
	24-36 (60-90)	1.0	1.1	9.6
			(μg NH_4^+-N/g)	
NH_4^+-N	0- 6 (0-15)	7.8	10.9	6.9
	6-12 (15-30)	8.1	7.4	4.6
	12-18 (30-45)	3.5	4.2	2.2
	18-24 (45-60)	2.9	1.4	1.4
	24-36 (60-90)	1.4	1.5	1.7
pH	0- 6 (0-15)	7.2	7.1	7.2
	6-12 (15-30)	7.2	7.3	7.1
	12-18 (30-45)	7.2	7.3	7.2
	18-24 (45-60)	7.3	7.2	7.2
	24-36 (60-90)	7.3	7.4	7.4

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* Data for one replication only.

TABLE 128. NO_3^--N Concentration in Sandy Loam Soil Profile (Cambridge; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 27, October 7 and November 15, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
			(µg NO_3^--N/g)					
June 27	0- 6	(0-15)	14.6	29.1	32.3	.01	.01	N.S.
	6-12	(15-30)	15.4	27.7	39.7			
	12-18	(30-45)	8.8	13.9	22.7			
	18-24	(45-60)	7.8	7.2	17.4			
	24-36	(60-90)	7.2	3.0	8.8			
Oct. 7	0- 6	(0-15)	7.5	11.5	14.7	.01	.05	N.S.
	6-12	(15-30)	7.8	15.5	39.1			
	12-18	(30-45)	3.4	18.2	15.4			
	18-24	(45-60)	2.7	5.5	5.9			
	24-36	(60-90)	1.9	3.3	6.0			
Nov. 15	0- 6	(0-15)	5.9	6.9	10.6	.01	.05	N.S.
	6-12	(15-30)	8.7	26.6	23.0			
	12-18	(30-45)	9.7	33.7	24.8			
	18-24	(45-60)	6.8	23.2	18.8			
	24-36	(60-90)	6.8	3.8	11.9			

* .05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 129. NO_3^--N Concentration in Silt Loam Soil Profile (Elora; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 24, October 1 and November 13, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	in	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				(μg NO_3^--N/g)				
June 24	0- 6	(0-15)	12.5	47.9	70.2	.01	.01	N.S.
	6-12	(15-30)	8.7	21.9	32.3			
	12-18	(30-45)	5.3	13.3	45.5			
	18-24	(45-60)	2.1	8.9	10.6			
	24-36	(60-90)	2.4	7.7	7.7			
Oct. 1	0- 6	(0-15)	6.5	54.9	99.4	.01	.01	.01
	6-12	(15-30)	1.3	9.7	37.2			
	12-18	(30-45)	0.3	5.5	10.1			
	18-24	(45-60)	1.3	3.8	10.5			
	24-36	(60-90)	2.9	2.9	5.7			
Nov. 13	0- 6	(0-15)	6.9	6.2	15.4	.01	.05	N.S.
	6-12	(15-30)	10.0	32.7	66.5			
	12-18	(30-45)	4.0	14.8	22.9			
	18-24	(45-60)	2.1	4.2	5.6			
	24-36	(60-90)	2.2	4.3	3.1			

* .05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 130. NO_3^--N Concentration in Clay Loam Soil Profile (Milton; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 28, October 4 and November 11, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
			(μg NO_3^--N/g)					
June 28	0- 6	(0-15)	27.7	37.4	79.9	.01	.01	.01
	6-12	(15-30)	10.1	20.6	18.6			
	12-18	(30-45)	8.1	9.2	14.7			
	18-24	(45-60)	7.5	6.2	12.1			
	24-36	(60-90)	5.5	3.8	6.9			
Oct. 4	0- 6	(0-15)	39.3	41.1	74.6	.01	.01	N.S.
	6-12	(15-30)	7.2	6.7	13.5			
	12-18	(30-45)	5.2	6.8	9.4			
	18-24	(45-60)	6.6	6.4	13.3			
	24-36	(60-90)	7.6	7.7	13.8			
Nov. 11	0- 6	(0-15)	35.8	50.5	69.5	.01	.01	.01
	6-12	(15-30)	7.9	9.1	15.0			
	12-18	(30-45)	3.1	1.5	5.9			
	18-24	(45-60)	1.6	1.5	4.7			
	24-36	(60-90)	2.7	5.3	4.9			

* .05 and .01 indicate level of significance.
N.S. indicates effect not significant at .05 level of probability.

TABLE 131. NO_3^--N Concentration in Silt Loam Soil Profile (Elora; Grass Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 18, September 30 and November 13, 1974.

Date	Depth In.	Depth (cm)	Sludge Rate-lb N/ac (kg N/ha) 0	356(400)	712(800)	Significance of Effect* Depth	Rate	D x R
				(μg NO_3^--N/g)				
June 18	0- 6	(0-15)	2.4	5.5	8.0	.01	N.S.	.05
	6-12	(15-30)	2.0	2.2	3.4			
	12-18	(30-45)	1.5	1.3	1.2			
	18-24	(45-60)	1.1	2.7	1.1			
	24-36	(60-90)	1.9	1.7	1.0			
Sept. 30	0- 6	(0-15)	3.0	7.3	23.4	.01	.01	.01
	6-12	(15-30)	2.5	2.4	5.9			
	12-18	(30-45)	1.3	2.0	2.1			
	18-24	(45-60)	1.8	2.1	4.0			
	24-36	(60-90)	2.1	1.2	2.0			
Nov. 13	0- 6	(0-15)	2.6	5.4	11.5	.01	.01	.01
	6-12	(15-30)	0.6	2.5	18.8			
	12-18	(30-45)	1.1	1.2	3.5			
	18-24	(45-60)	0.5	1.4	0.7			
	24-36	(60-90)	1.5	1.2	0.4			

*.05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 132. NH_4^+-N Concentration in Sandy Loam Soil Profile (Cambridge; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 27, October 7 and November 15, 1974.

Date	Depth		Sludge Rate-lb N/ac (Kg N/ha)			Significance of Effect*		
	in	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
			(μg NH_4^+-N/g)					
June 27	0- 6	(0-15)	5.2	7.3	8.8	.01	.05	N.S.
	6-12	(15-30)	4.2	2.7	6.1			
	12-18	(30-45)	2.2	3.9	3.3			
	18-24	(45-60)	2.3	3.3	3.7			
	24-36	(60-90)	1.3	3.3	2.7			
Oct. 7	0- 6	(0-15)	6.1	8.0	8.8	.01	N.S.	N.S.
	6-12	(15-30)	2.9	3.8	2.9			
	12-18	(30-45)	1.8	2.2	2.9			
	18-24	(45-60)	0.9	1.0	0.5			
	24-36	(60-90)	0.5	0.5	0.7			
Nov. 15	0- 6	(0-15)	2.9	2.9	3.5	.01	N.S.	N.S.
	6-12	(15-30)	2.0	2.9	2.2			
	12-18	(30-45)	1.3	1.7	1.3			
	18-24	(45-60)	0.6	1.1	0.9			
	24-36	(60-90)	0.6	0.8	0.9			

* .05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 133. NH_4^+-N Concentration in Silt Loam Profile (Elora; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 24, October 1 and November 13, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				(μg NH_4^+-N/g)				
June 24	0- 6	(0-15)	7.8	8.9	10.0	.01	.01	N.S.
	6-12	(15-30)	5.1	3.6	6.4			
	12-18	(30-45)	3.7	4.3	6.7			
	18-24	(45-60)	2.7	1.9	5.4			
	24-36	(60-90)	2.0	1.2	3.7			
Oct. 1	0- 6	(0-15)	5.5	5.9	7.3	.01	N.S.	N.S.
	6-12	(15-30)	4.3	4.0	4.2			
	12-18	(30-45)	1.9	2.4	2.6			
	18-24	(45-60)	1.3	1.6	1.8			
	24-36	(60-90)	1.1	1.3	1.3			
Nov. 13	0- 6	(0-15)	2.8	3.9	3.8	.01	N.S.	N.S.
	6-12	(15-30)	2.0	2.8	2.6			
	12-18	(30-45)	1.3	1.6	1.9			
	18-24	(45-60)	1.2	0.9	1.0			
	24-36	(60-90)	0.7	1.0	0.6			

* .05 and .01 indicate level of significance.

N.S. indicateseffect not significant at .05 level of probability.

TABLE 134. NH_4^+-N Concentration in Clay Loam Soil Profile (Milton; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 28, October 4 and November 11, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				(μg NH_4^+-N/g)				
June 28	0- 6	(0-15)	9.3	8.8	26.4	.01	.01	.01
	6-12	(15-30)	4.6	4.7	5.2			
	12-18	(30-45)	2.9	1.3	2.0			
	18-24	(45-60)	1.6	0.8	1.1			
	24-36	(60-90)	1.2	0.6	0.9			
Oct 4	0- 6	(0-15)	2.4	4.3	4.2	.01	.01	.01
	6-12	(15-30)	1.5	1.8	1.9			
	12-18	(30.45)	0.8	1.0	1.4			
	18-24	(45-60)	0.6	1.1	0.9			
	24-36	(60-90)	0.3	0.7	0.7			
Nov 11	0- 6	(0-15)	3.8	4.9	7.5	.01	.05	N.S.
	6-12	(15-30)	2.5	3.1	3.7			
	12-18	(30-45)	1.6	1.3	2.2			
	18-24	(45-60)	1.2	0.8	1.1			
	24-36	(60-90)	0.7	0.8	0.9			

* .05 and .01 indicate level of significance N.S. indicates effect not significant at .05 level of probability.

TABLE 135. NH_4^+-N Concentration in Silt Loam Soil Profile (Elora; Grass Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 18, September 30 and November 13, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	in	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				(μg NH_4^+-N/g)				
June 18	0- 6	(0-15)	6.3	7.9	10.1	.01	.01	N.S.
	6-12	(15-30)	4.0	4.3	5.6			
	12-18	(30-45)	1.9	1.6	2.1			
	18-24	(45-60)	0.9	1.0	1.8			
	24-36	(60-90)	0.7	0.6	1.3			
Sept. 30	0- 6	(0-15)	4.0	6.0	7.6	.01	.01	N.S.
	6-12	(15-30)	3.1	3.8	6.1			
	12-18	(30-45)	1.6	2.2	2.6			
	18-24	(45-60)	1.4	1.8	2.9			
	24-36	(60-90)	1.0	1.4	1.1			
Nov. 13	0- 6	(0-15)	6.8	14.3	12.4	.01	N.S.	N.S.
	6-12	(15-30)	12.3	5.7	7.0			
	12-18	(30-45)	2.6	3.0	14.5			
	18-24	(45-60)	1.7	1.9	2.6			
	24-36	(60-90)	1.6	2.0	1.9			

* .05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 136. pH of Sandy Loam Soil Profile (Cambridge; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 27, October 7 and November 15, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	in	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
June 27	0- 6	(0-15)	7.6	7.0	7.3	.01	.01	N.S.
	6-12	(15-30)	7.5	7.2	7.4			
	12-18	(30-45)	7.7	7.5	7.6			
	18-24	(45-60)	7.9	7.7	7.8			
	24-36	(60-90)	8.0	7.8	7.9			
Oct. 7	0- 6	(0-15)	7.6	7.5	7.5	.01	N.S.	N.S.
	6-12	(15-30)	7.5	7.5	7.6			
	12-18	(30-45)	7.6	7.6	7.7			
	18-24	(45-60)	7.8	7.8	7.9			
	24-36	(60-90)	7.9	7.9	7.9			
Nov. 15	0- 6	(0-15)	7.8	7.5	7.6	.01	.05	.01
	6-12	(15-30)	7.7	7.5	7.8			
	12-18	(30-45)	7.8	7.7	7.9			
	18-24	(45-60)	7.9	7.9	7.9			
	24-36	(60-90)	7.9	8.2	8.1			

* .05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 137. pH of Silt Loam Soil Profile (Elora; Corn Experiment) in Plots having Received Quantities of Fe-treated Sludge. Sampled June 24, October 1 and November 13, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ac)			Significance of Effect*		
	in	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
June 24	0- 6	(0-15)	7.5	7.5	7.1	.01	.01	N.S.
	6-12	(15-30)	7.5	7.7	7.5			
	12-18	(30-45)	7.6	7.7	7.5			
	18-24	(45-60)	7.8	7.9	7.8			
	24-36	(60-90)	7.9	8.0	7.9			
Oct. 1	0- 6	(0-15)	7.7	7.5	7.3	.01	.01	.05
	6-12	(15-30)	7.6	7.7	7.5			
	12-18	(30-45)	7.8	7.8	7.7			
	18-24	(45-60)	7.9	7.9	7.8			
	24-36	(60-90)	7.9	7.9	7.9			
Nov. 13	0- 6	(0-15)	7.7	7.6	7.5	.01	.01	N.S.
	6-12	(15-30)	7.6	7.5	7.4			
	12-18	(30-45)	7.7	7.6	7.5			
	18-24	(45-60)	7.8	7.8	7.7			
	24-36	(60-90)	7.9	7.8	7.8			

* .05 and .01 indicate level of significance.
N.S. indicates effect not significant at .05 level of probability.

TABLE 138. pH of Clay Loam Soil Profile (Milton; Corn Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled on June 28, October 4 and November 11, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	in	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
June 28	0- 6	(0-15)	7.0	7.1	6.8	.01	N.S.	N.S.
	6-12	(15-30)	6.9	6.8	6.6			
	12-18	(30-45)	7.4	7.5	7.3			
	18-24	(45-60)	7.6	7.9	7.7			
	24-36	(60-90)	8.0	7.9	7.9			
Oct. 4	0-6	(0-15)	6.7	6.8	6.6	.01	N.S.	N.S.
	6-12	(15-30)	6.5	6.7	6.5			
	12-18	(30-45)	7.5	7.5	7.5			
	18-24	(45-60)	7.7	7.7	7.7			
	24-36	(60-90)	7.7	7.8	7.7			
Nov. 11	0-6	(0-15)	6.8	6.6	6.7	.01	N.S.	N.S.
	6-12	(15-30)	6.7	6.6	6.7			
	12-18	(30-45)	7.5	7.3	7.5			
	18-24	(45-60)	7.8	7.7	7.7			
	24-36	(60-90)	7.8	7.8	7.8			

* .05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 139. pH of Silt Loam Soil Profile (Elora; Grass Experiment) in Plots having Received Different Quantities of Fe-treated Sludge. Sampled June 18, September 30 and November 13, 1974.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	in	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
June 18	0- 6	(0-15)	7.8	7.7	7.7	.01	N.S.	N.S.
	6-12	(15-30)	7.8	7.7	7.8			
	12-18	(30-45)	7.9	7.8	7.9			
	18-24	(45-60)	7.8	7.9	7.9			
	24-36	(60-90)	8.1	8.0	7.9			
Sept. 30	0- 6	(0-15)	7.7	7.6	7.6	.01	N.S.	.05
	6-12	(15-30)	7.7	7.7	7.7			
	12-18	(30-45)	7.7	7.8	7.8			
	18-24	(45-60)	7.7	7.8	7.8			
	24-36	(60-90)	7.9	7.9	8.2			
Nov. 13	0- 6	(0-15)	7.7	7.6	7.5	.01	N.S.	N.S.
	6-12	(15-30)	7.6	7.7	7.6			
	12-18	(30-45)	7.8	7.7	7.7			
	18-24	(45-60)	7.8	7.9	7.8			
	24-36	(60-90)	7.9	8.0	7.9			

* .05 and .01 indicate level of significance.

N.S. indicates effect not significant at .05 level of probability.

TABLE 140. Quantity of NH_4^+-N (Soluble + Exchangeable) Applied per each 100 kg Total Sludge N per hectare of Each Sludge Applied at Each of Four Sites in 1974.

Site	(Crop)	NH_4^+-N applied per 100 kg total sludge N/hectare Calcium Sludge	 Aluminum Sludge	 Iron Sludge
			(kg NH_4^+-N/ha)	
Elora	(corn)	21	41	36
Elora	(grass)	29	45	34
Cambridge	(corn)	19	44	29
Milton	(corn)	20	42	32

TABLE 141. NO_3^--N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Cambridge Corn Experiment (sandy loam) on June 27, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			(μg NO_3^--N/g)		
89 (100)	29b*				
356 (400)	64a	22b	28b	29b	26
712 (800)		34b	33b	32b	33

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Ammonium nitrate treatments data are significantly different at 0.01 probability by "F" test.

TABLE 142. NO_3^--N Concentration of 0-6 in (0-15 cm) Soil Samples Taken from Elora Corn Experiment (silt loam) on June 24, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			NO_3^--N $\mu g/g$		
89 (100)	33d*				
356 (400)	116b	31d	78bc	48cd	52
712 (800)		69cd	167a	70cd	102
Average					

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Sludge sources and rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 143. NO_3^--N Concentration in 0-6 (0-15 cm) Soil Samples Taken from Milton Corn Experiment (clay loam) on June 28, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			(μg NO_3^--N/g)		
89 (100)	49bc*				
356 (400)	103a	30c	42c	37c	36
712 (800)		31c	79ac	80ab	63

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Ammonium nitrate data and sludge rates are significantly different at 0.01 probability and sludges at 0.05 probability by "F" test.

TABLE 144. NO_3^--N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Elora Grass Experiment (silt loam) on June 19, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			(μg NO_3^--N/g)		
89 (100)	2b*				
356 (400)	4ab	2b	2b	6ab	3
712 (800)		5ab	13a	8ab	8

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Sludge rates are significantly different at 0.05 probability by "F" test.

TABLE 145. NH_4^+-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Cambridge Corn Experiment (sandy loam) on June 27, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			(μg NH_4^+-N/g)		
89 (100)	9b*				
356 (400)	6b	8b	8b	7b	8
712 (800)		9b	15a	9b	11

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Ammonium nitrate treatment data and sludge rate are significantly different at 0.05 probability by "F" test.

TABLE 146. NH_4^+-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Elora Corn Experiment (silt loam) on June 24, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			(μg NH_4^+-N/g)		
89 (100)	13cde*				
356 (400)	12cde	17b	16bc	9e	14
712 (800)		15bcd	29a	10e	18

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Sludge sources, rates and sludge x rate intersection are significantly different at 0.01 probability by "F" test.

TABLE 147. NH_4^+-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Milton Corn Experiment (clay loam) on June 28, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			(μg NH_4^+-N/g)		
89 (100)	9c*				
356 (400)	39a	13bc	15bc	9c	12
712 (800)		14bc	23bc	26ab	21

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Ammonium nitrate data are significantly different at 0.01 probability and sludge rate at 0.05 probability by "F" test.

TABLE 148. NH_4^+-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Elora Grass Experiment (silt loam) on June 19, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			(μg NH_4^+-N/g)		
89 (100)	12bcd				
356 (400)	12bcd	11bcd	15abc	8d	11
712 (800)		16ab	19a	10cd	15

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Sludge sources and sludge rates are significantly different at 0.01 probability by "F" test.

TABLE 149. pH in 0-6 in (0-15 cm) Soil Samples taken from Cambridge Corn Experiment (sandy loam) on June 27, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Sources **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
89 (100)	7.4b*				
356 (400)	7.4b	8.1a	7.4b	7.0b	7.5
712 (800)		8.0a	7.3b	7.2b	7.5

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Sludges are significantly different at 0.01 probability by "F" test.

TABLE 150. pH in 0-6 in (0-15 cm) Soil Samples taken from Elora Corn Experiment (silt loam) on June 24, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitorgen Sources **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
89 (100)	7.6b*				
356 (400)	7.4bc	7.9a	7.3bc	7.5b	7.6
712 (800)		7.9a	7.3bc	7.1c	7.4

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Sludge sources are significantly different at 0.01 probability by "F" test.

TABLE 151. pH in 0-6 in (0-15 cm) Soil Samples taken from Milton Corn Experiment (clay loam) on June 28, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Sources **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
89 (100)	6.8b*				
356 (400)	6.2c	7.8a	6.7bc	7.0b	7.2
712 (800)		7.7a	6.8b	6.8b	7.1

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Ammonium nitrate data and sludges are significantly different at 0.01 probability by "F" test.

TABLE 152. pH in 0-6 in (0-15 cm) soil Samples taken from Elora Grass Experiment (silt loam) on June 19, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Sources **				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
89 (100)	7.6cd*				
356 (400)	7.5cd	7.9ab	7.5cd	7.7bc	7.7
712 (800)		8.0a	7.4d	7.7bc	7.7

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Sludge sources are significantly different at 0.01 probability by "F" test.

TABLE 153. Nitrate Concentration of Subsurface Water Samples in Fall, 1974.

Site	Treatment	12/8/74	21/10/74	4/11/74	18/11/74	2/12/74	17/12/74	31/12/74
				DATE				
				($\mu g\ NO_3^- - N/ml$)				
Runoff	100 kg N/ha (NH_4NO_3)	12 (4)*		7 (1)		9 (2)	9 (3)	6 (3)
Experiment	800 kg N/ha (Fe-sludge)	17 (3)				39 (4)		22 (4)
Corn	100 kg N/ha (NH_4NO_3)	59 (3)	19 (2)	19 (2)	36 (2)	40 (3)	44 (1)	39 (1)
Experiment	200 kg N/ha (NH_4NO_3)				56 (2)	93 (2)	205 (1)	150 (1)
	400 kg N/ha (NH_4NO_3)	15 (3)	25 (2)	37 (2)		49 (3)		
	200 kg N/ha (Fe-sludge)	13 (3)	12 (1)	14 (2)	22 (2)	31 (3)	24 (2)	39 (2)
	400 kg N/ha (Fe-sludge)	49 (3)	5 (1)	19 (1)	27 (1)	68 (3)	67 (2)	102 (3)
	800 kg N/ha (Fe-sludge)	24 (3)	11 (2)	22 (3)	28 (2)	65 (2)	75 (1)	75 (1)
	1600 kg N/ha (Ca-sludge)**				141 (2)	155 (2)	215 (2)	235 (1)
	1600 kg N/ha (Al-sludge)**				188 (2)	269 (2)	400 (1)	270 (1)
	1600 kg N/ha (Fe-sludge)**					295 (3)	283 (2)	253 (2)

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* Number in parenthesis indicates number of samples representing the mean value.

** 1.5 foot depth.

TABLE 154. Chloride Concentration of Subsurface Water Samples in Fall, 1974

Site	Treatment	Date						
		12/8/74	21/10/74	4/11/74	18/11/74	2/12/74	17/12/74	31/12/74
				(µg Cl-/ml)				
Runoff Experiment	100 kg N/ha (NH_4NO_3)	22 (4)*		14 (1)		13 (2)	18 (3)	16 (3)
	800 kg N/ha (Fe-sludge)	26 (3)				23 (4)		19 (4)
Corn Experiment	100 kg N/ha (NH_4NO_3)	56 (3)	35 (2)	28 (2)	30 (2)	34 (3)	29 (1)	37 (1)
	200 kg N/ha (NH_4NO_3)				76 (2)	118 (2)	56 (1)	33 (1)
	400 kg N/ha (NH_4NO_3)	23 (3)	12 (2)	17 (2)		19 (3)		
	200 kg N/ha (Fe-sludge)	20 (3)	17 (1)	16 (2)	15 (2)	28 (3)	25 (2)	38 (2)
	400 kg N/ha (Fe-sludge)	32 (3)	18 (1)	20 (1)	17 (1)	42 (3)	49 (2)	66 (3)
	800 kg N/ha (Fe-sludge)	29 (3)	15 (2)	18 (3)	16 (2)	53 (2)	49 (1)	61 (1)
	1600 kg N/ha (Ca-sludge)**				124 (2)	118 (2)	105 (2)	105 (1)
	1600 kg N/ha (Al-sludge)**				145 (2)	121 (2)	195 (1)	102 (1)
	1600 kg N/ha (Fe-sludge)**					120 (3)	176 (2)	162 (2)

* Number in parenthesis indicates number of samples representing the mean value.

** 1.5 foot depth.

TABLE 155. The Rate of NO_3^--N Production in Incubated Soil Treated with Three Sludges in the Laboratory During the 18th to 52nd week Period (Experiment 1).

Sludge Treatment	Week 19 to 26	Week 27 to 40	Week 41 to 52
		(μg NO_3^--N/g soil/week)	
Iron sludge	13.9	4.4	4.4
Calcium sludge	12.2	8.9	5.0
Aluminum sludge	3.9	8.9	3.9

TABLE 156. NO_3^--N Concentrations in the Leachates from Soil Mixed with Organic N from Different Sludges After Weekly Incubation Periods (Experiment 3).

Sludge Source	Week 1	Week 2
	(μg NO_3^--N/g soil)	
Kitchener	24	60
North Toronto	21	47
Point Edward	20	4
Newmarket	18	20
Guelph	21	59
Untreated soil	20	23

TABLE 157. NO_3^--N Concentration in Soil (after the first ryegrass harvest in the greenhouse study) Treated with Different Rates of Sludge N with Nine Different Sludges.

Sludge Source	Percent NH_4^+-N of Total N in Sludge	Rate of Application (kg total N/ha) 200	400	1600
			(μg NO_3^--N/g)	
Aurora	7.4	0.5	6.4	49.8
Midland	9.9	0.3	4.0	59.0
Point Edward	12.0	4.5	10.6	193.1
Sarnia	46.0	0.4	32.5	102.6
Guelph	46.0	31.7	53.5	252.1
Fergus	49.0	2.9	112.1	185.4
North Toronto	34.0	1.8	47.4	139.4
Newmarket	47.0	18.2	35.9	236.7
Toronto Humber	47.0	6.5	64.1	335.5

Check (100 kg N/ha as NH_4NO_3) = 1.5 μg NO_3^--N/g

Significance of F values at probability shown:

Sludges 0.01
Sludge N Rates 0.04
Sludges x Sludge N Rates 0.01

TABLE 158. Exchangeable NH_4^+-N Concentration in Soil (after the first ryegrass harvest in the greenhouse study) Treated with Different Rates of Sludge N from Nine Different Sludges

Sludge Source	Percent NH_4^+-N of Total N in Sludge	Rate of Application (kg total N/ha) 200	400	1600
			(μg NH_4^+-N/g)	
Aurora	7.4	2.5	7.8	9.8
Midland	9.9	4.0	10.0	12.4
Point Edward	12.0	3.5	7.9	10.2
Sarnia	46.0	3.0	3.8	10.7
Guelph	46.0	3.0	7.2	9.7
Fergus	49.0	3.8	3.6	24.6
North Toronto	34.0	4.6	6.1	11.1
Newmarket	47.0	6.6	7.3	10.0
Toronto Humber	47.0	3.3	6.0	14.4

Check (100 kg N/ha as NH_4NO_3) = 2.1 μg NH_4^+-N/g

Significance of F values:

Sludges .01
Sludge N Rates .01
Sludges x Sludge N Rates .01
Soil pH .01
Sludges x pH .01
Sludge N Rates x pH .01
Sludges x Sludge N Rates x pH .01

6 GREENHOUSE STUDIES

6.1 Greenhouse Experiment 1

6.1.1 Objectives

1) To determine the effect of various sewage sludges on crop growth.
2) To determine the effect of metals in sewage sludge on metal uptake by plants.
3) To determine the availability of nitrogen in sewage sludges.

6.1.2 Materials and methods

The soil used in this study was a Grimsby sandy loam soil of pH 4.6 which was limed to two pH levels, approximately 5.0 and 7.0 using reagent grade $CaCO_3$. The three sewage sludges used in the field trials were applied to these soils along with six other Ontario sludges selected because of their high metal content (Table 159). Sludges were applied at rates supplying 0, 178, 712 and 1424 lb N/ac (0,200, 800 and 1600 kg N/ha). Fertilization of the check treatment and dates of seeding and harvest are shown in Table 160. Ryegrass was grown on the soils in greenhouse pots and the yield, nutrient and metal content of the crop were measured. Nitrogen content of the soils was also monitored to measure the availability of nitrogen in the sludge.

A second crop has been grown and it is intended to continue cropping and applying sludge for several cycles. Half of the pots receiving the highest rate of sludge received only one application and are being cropped without further additions.

6.1.3 Results and discussion

Nutrient and metal content of sludges used in the first three applications of sludges in this experiment are presented in Tables 161 to 166. Analyses of the sludges for the third application (Table 166) present the first data from this project on molybdenum (Mo) and selenium (Se) content of sludges. Cumulative amounts of nutrients and metals applied in the first two applications of sludge are presented in Tables 167 and 168.

Dry matter yields of the first and second crops of annual ryegrass are presented in Tables 169 and 170. Raising the soil pH from 5.0 to 7.0 before application of the sludges increased the yield of the first crop of ryegrass. In the first crop all sludges appeared to increase yield when compared to the check treatment which received commercial fertilizer. The check treatment received 89 lb N/ac (100 kg/ha) but the plants showed nitrogen deficiency symptoms as harvest time approached. There is little doubt that yield response to sludge was partly due to nitrogen. The highest rates of the Point Edward, Guelph, Fergus and Newmarket sludges produced lower yields than lower rates of application. This was most pronounced with the Fergus sludge.

In the second crop of ryegrass, all sludge except North Toronto reduced the yield when applied at high rates.

Conductivity measurements on the saturation extracts from soils showed that salinity was a problem during the growth of the second crop. The pots have been leached before seeding the third crop but the interpretation of both yield and chemical composition data from the second crop is difficult because salinity probably affected growth, and nutrient and metal uptake. Electrical conductivity of the 1600 kg N/ha treatment (reapplied for each crop) measured after leaching and the third sludge addition is presented in Table 171. These values show that the Fergus and Guelph sludges added most to soil salinity. Conductivity values above 4000 μ mho are considered unfavourable for plant growth. Because of these high conductivity values with most sludges it is now intended to leach all pots after each sludge addition.

Soil pH values of 5.0 and 7.0 presented in most tables were those to which the soil was adjusted before addition of the sludges. The pH values at the time of harvest of the second crop of ryegrass are presented in Table 172. Two applications of the sludges have maintained soil pH at levels above those where no sludge was applied and ammonium nitrate was used to supply nitrogen.

In the first crop, nitrogen concentrations increased with rate of all sludges (Table 173) but the size of the increase varied among sludges. The Aurora and Midland sludges, which supplied less soluble nitrogen to the first crop (Table 161), provided the lowest nitrogen concentration in the grass at the lowest rate of application. The higher soil pH also produced high nitrogen concentrations in the ryegrass.

In the second crop of ryegrass, differences in nitrogen concentration between sludges were not significant (Table 174), but the lowest rate of sludges resulted in lower nitrogen concentrations.

All the sludges resulted in higher concentrations of phosphorus in the first ryegrass crop than the check treatment which received 102 lb P_2O_5/ac (50 kg P/ha) (Table 175). The increase in phosphorus, due to sludge application was not consistent in the second crop (Table 176).

Potassium concentrations in the ryegrass were increased by increasing rates of sludges in the first crop (Table 177) but not in the second crop. The effect of pH was statistically significant but small.

Calcium and magnesium concentrations in the ryegrass were increased by all the sludges, although the effect of rates of sludge was not very consistent (Tables 179, 180, 181 and 182). Calcium concentration was highest with the calcium sludge from Newmarket, as might be expected, but it was also high with Point Edward sludge which was not high in calcium.

Boron concentrations in the first crop were affected by sludge application (Table 183), the Midland sludge adding 4.0 kg B/ha at the highest rate, markedly increasing the B content of the grass. This is a greater application of boron than is normally recommended even for crops with a high boron requirement grown on boron deficient soils. While moderate rates of such a sludge would prevent boron deficiency under Ontario conditions they might cause toxicity in dry areas where boron tends to accumulate. The sludge resulting from lime treatment of sewage (Newmarket), while adding an appreciable amount of boron, reduced the B concentration in the first crop of grass quite appreciably. Boron concentration in the second crop of ryegrass was not affected by treatment.

Cadmium concentrations in both crops of ryegrass (Tables 184 and 185) were greatly increased by the sludges which were high in cadmium even when applied at the lowest rate of application. Where sludges high in cadmium were applied, the cadmium concentration was highest with the soil at pH 5.0 in the first crop, but this effect was not consistent with the low cadmium sludges, nor in the second crop. Cadmium in the second crop was much higher when one sludge application at the rate of 1600 kg N/ha was applied before the first crop was planted than where a second application was also applied, and much higher than where two applications of 800 kg N/ha were applied.

Differences in chromium concentrations in the ryegrass were statistically significant but too small to be of practical concern in spite of rather large applications of chromium (Tables 186 and 187).

All sludges increased copper concentrations in the ryegrass markedly (Tables 188 and 189) and liming the soil to pH 7.0 only reduced copper content in the first crop, and to a minor extent. Copper content in the first crop was, in general, related to the amount of copper added in the different sludges. There were exceptions, however; the Guelph sludge, for example, supplied less than half as much copper as the Fergus sludge but resulted in similar concentrations in the ryegrass. In the second crop, Point Edward sludge produced a very high copper concentration in the grass in spite of a relatively small addition of copper. It is possible that the poor growth of grass with the Fergus sludge in the first crop (Table 169) was due to copper toxicity but the electrical conductivity data (Table 171) suggest that salinity of the soil is an equally plausible reason for the poor growth.

Iron and manganese concentrations in ryegrass were affected by treatment (Tables 190, 191, 192 and 193) but no particular concern appears warranted except at low soil pH where sludge application could increase the danger of manganese toxicity. At the low pH the manganese concentration probably approached the point of toxicity in the second crop where no sludge was applied. Manganese concentrations in Table 193 appear to be correlated with soil pH values (Table 172).

Nickel concentrations in the ryegrass were increased by a factor of 10 where the Midland sludge was applied (Tables 194 and 195) as might be expected from the very high nickel additions with the Midland sludge (Table 168). This occurred in spite of the high soil pH maintained with this limed sludge (Table 172). The Toronto Humber sludge caused quite high nickel concentrations in the ryegrass with much lower nickel additions, but also lower soil pH than where the Midland sludge was applied. The 1600 kg N/ha rate of sludge applied only once resulted in higher nickel concentrations in the second grass crop than either two applications of the 800 kg N/ha rate or two applications of the 1600 kg N/ha rate. This difference appears to be related to differences in soil pH to some extent.

Zinc concentrations in the ryegrass were increased markedly (Tables 196, 197 and 198) by addition of sludges high in zinc (Table 168). Some of the sludges low in zinc actually reduced the zinc concentration in ryegrass, perhaps by raising the soil pH (Table 172). At low soil pH, the one addition of sludges at 1600 kg N/ha resulted in markedly higher zinc concentrations in the second crop of ryegrass than two additions of either the 800 or 1600 kg N/ha rate. This effect was only apparent with treatments resulting in high zinc concentrations (Table 197).

Aluminum concentrations in ryegrass were affected by sludge additions, but only to a limited extent (Tables 199 and 200). Lead concentrations in the first crop of ryegrass were reduced slightly by most sludges. In the second crop of ryegrass, treatments affected lead content significantly but the differences were small.

6.2 Greenhouse Experiment 2

Fifty-four soils were used in this experiment. Most of these soils were collected from sites believed to vary in copper and cadmium content. Soils were collected near snow dumps, industrial waste disposal sites and old orchards. The soil which received the highest rate of different sludges in greenhouse experiment 1 was also included in this experiment.

To stabilize soils collected from virgin sites a crop of ryegrass was grown in all the soils for one month before the main experiment was started. After harvest of the ryegrass a sample of each soil was taken for chemical analysis and soils were prepared for planting Swiss chard.

The soils were analysed for organic matter, cation exchange capacity, clay, soil pH, phosphorus potassium and magnesium. Field capacity of each soil was also determined.

Swiss chard was planted on July 18, 1974. Phosphorus, potassium and magnesium were added in each soil based on analyses from the soil testing laboratory of the Ontario Ministry of Agriculture and Food. Nitrogen as NH_4NO_3 was added at the rate of 200 kg N/ha in four applications of 50 kg N/ha each at approximate weekly intervals.

Five extractants were tested as a measure of soil available Cu, Cd, Ni and Pb (Table 201). The average value and range of soil and plant variables are shown in Table 202.

6.2.1 Cadmium

The most important soil variable affecting the uptake of cadmium was the soil pH. Acetic acid extractable Cd along with the soil pH could explain 56% of variability in the Cd concentration in Swiss chard. Soil pH had a negative linear correlation which indicates that an increase in soil pH will result in decrease in Cd concentration in plants. Similar results were obtained with water extractable Cd which had an $R^2 = 0.887$ when several variables were included along with extracted cadmium. The R^2 values for other extractants are EDTA, 0.63, aqua regia, 0.667; and DTPA, 0.743.

6.2.2 Copper

In multiple regression analyses the most important soil variable which entered at the first step was soil pH, which had negative linear correlation ($r = 0.55$). The addition of further variables in the regression equation did not improve R^2 significantly. Similar patterns were obtained when EDTA, water extractable Cu, aqua regia and DTPA extractable Cu were related to the Cu concentration in Swiss chard. The R^2 values obtained for various extractants are as follows:

EDTA - 0.485, Water - 0.535, Aqua regia - 0.463, and DTPA - 0.488.

6.2.3 Nickel

All the extractants except DTPA showed a significant correlation with the Ni concentration in Swiss chard. The prediction equations using various extractants are shown below:

Acetic Acid

$\hat{Y} = 0.1941 - 0.13\ DM \times pH - 0.699\ clay \times Ni + 0.87\ Ni^2$ $R^2 = 0.86$

EDTA

$\hat{Y} = 0.205 - 0.87\ clay \times Ni - 0.33\ pH^2 + 0.68\ Ni^2$ $R^2 = 0.83$

Water

$\hat{Y} = 0.558 + 0.26\ CM \times Ni - 0.77\ CEC \times Ni + 0.37\ Ni^2$ $R^2 = 0.73$

Aqua regia

$\hat{Y} = 0.416 - 0.24\ DM \times Ni + 0.66\ pH \times Ni - 0.17\ CEC \times Ni$ $R^2 = 0.79$

DTPA

$R^2 = 0.12$

6.2.4 Zinc

None of the Zn extractants showed promising results. The important soil variables which entered in various equations were soil pH and organic matter. The equation developed by using acetic acid extractable Zn along with the soil pH and organic matter had an R^2 value of 0.719, compared with EDTA - 0.645, water extractable Zn - 0.511, DTPA - 0.599, and aqua regia - 0.345.

6.2.5 Conclusions

The data from this experiment require further study and further extractants will be tested. The soils in this experiment and the concentrations of metals in the Swiss chard appear to provide a fairly adequate range and distribution of values for testing extractants.

The acetic acid extraction appears to offer considerable promise as a test for plant available nickel. More work is required on the other metals.

TABLE 159. Sewage Sludges Used in Greenhouse Experiment 1.

Sewage Plant	Date Collected	P Removal Chemical	Sludge Digestion	Type of Sewage Treatment
1. Aurora	18/1/74	Alum (June 17/74)	yes	Secondary
2. Midland	17/1/74	Lime (Jan 2/74)	yes	Primary
3. Point Edward	15/1/74	Ferric Chloride	yes	Primary
4. Sarnia	15/1/74	Ferric Chloride	yes	Primary
5. Guelph	22/1/74	{Aluminum sulfate(Feb 1/74) Ferric Chloride (Feb /75)}	yes	Secondary
6. Fergus	21/1/74	Ferric Chloride (Apr 1/74)	yes	Secondary
7. N. Toronto	4/1/74	Ferric Chloride	yes	Secondary
8. Newmarket	4/1/74	Lime	yes	Secondary
9. Toronto Humber	18/1/74	None	yes	Secondary

TABLE 160. Treatments Applied to Greenhouse Experiment 1.

Treatment Applied	1st Crop	2nd Crop	3rd Crop
	Fertilizer applied to check plots		
46% super phosphate before seeding	102 lb P_2O_5/ac	83 lb P_2O_5/ac	
	(50 kg P/ha)	(40 kg P/ha)	
Magnesium sulfate	17.8 lb Mg/ac	35.6 lb Mg/ac	
	(20 kg Mg/ha)	(40 kg Mg/ha)	
Ammonium nitrate	89 lb N/ac*	178 lb N/ac**	
	(100 kg N/ha)	(200 kg N/ha)	
	Cultural Operations		
Sludge Additions	Feb 20-Mar 9 1974	June 1-30, 1974	
Seeding dates	March 14, 1974	September 5, 1974	
Harvest dates	April 23, 1974	October 11, 1974	

* Applied in two equal applications

** Applied in four equal applications at a seeding and approximately weekly.

TABLE 161. Concentrations of Various Constituents in Nine Ontario Fluid Sewage Sludges used in 1974 Greenhouse Experiment 1. (First Application)

Treatment Plant	D.M. %	NITROGEN Total %	 Soluble µg/g	 Exch µg/g	P %	K µg/g	Ca µg/g	Mg µg/g	Na µg/g	B µg/g
Aurora	1.7	0.10	50	24	0.08	40	1100	110	161	2
Midland	3.8	0.11	80	29	0.21	38	3150	277	96	3
Point Edward	3.6	0.15	170	16	0.09	46	3250	309	86	1
Sarnia	2.3	0.13	550	55	0.13	49	850	227	50	1
Guelph	3.0	0.17	775	23	0.08	78	1750	300	188	1
Fergus	3.7	0.22	1050	46	0.06	82	1850	471	684	1
North Toronto	6.0	0.30	950	83	0.29	120	2200	420	102	1
Newmarket	5.3	0.10	450	22	0.06	71	9900	315	143	1
Toronto Humber	2.9	0.17	775	25	0.08	120	1450	204	153	1

TABLE 162. Metal Concentration in Nine Ontario Fluid Sewage Sludges used in 1974 Greenhouse Experiment 2. (First Application)

Treatment Plant	Al	Fe	Mn	Cd	Cr µg/g	Cu	Ni	Pb	Zn
Aurora	1487	122	3.8	0.24	194.00	7.0	2.79	5.8	6.8
Midland	670	689	16.1	0.82	107.00	31.0	325.00	80.4	68.9
Point Edward	200	446	19.5	0.20	0.97	27.0	0.55	34.6	31.9
Sarnia	134	1864	76.9	2.56	2.87	19.0	0.69	86.2	314.5
Guelph	71	750	7.1	7.50	132.00	99.0	3.36	45.0	262.5
Fergus	116	463	10.9	2.66	142.00	277.0	2.96	15.1	537.0
North Toronto	810	5700	27.3	2.49	48.00	93.0	2.10	120.0	225.0
Newmarket	179	450	25.1	0.21	1.30	16.4	0.26	9.4	42.3
Toronto Humber	285	1022	10.6	4.35	95.60	46.7	16.80	7.7	186.9

TABLE 163. Concentration of Various Constituents in Second Application of Nine Ontario Fluid Sewage Sludges used in 1974 Greenhouse Experiments.

Sludge	pH	DM %	N %	Available N µg/g	P %	K %	Ca %	Mg %	Na %	B µg/g
Aurora	7.1	4.27	.13	710	.06	.01	0.32	.02	.017	2
Midland	7.3	5.42	.07	170	.17	.01	0.89	.05	.007	2
Pt. Edward	7.1	19.40	.30	650	.83	.04	1.94	.14	.010	2
Sarnia	7.2	5.89	.14	460	.15	.03	0.29	.08	.009	1
Guelph	7.2	4.70	.13	650	.17	.01	0.28	.03	.013	1
Fergus	7.4	3.70	.21	930	.08	.02	0.26	.06	.03	1
North Toronto	7.2	7.71	.29	1050	.33	.03	0.34	.05	.023	1
Newmarket	7.1	14.69	.17	590	.13	.02	3.64	.06	.013	1
Toronto Humber	7.2	7.29	.32	1050	.24	.03	0.39	.05	.015	2

TABLE 164. Metal Concentration in Second Application of Nine Ontario Fluid Sewage Sludges used in 1974 Greenhouse Experiments.

Sludge	Al	Fe	Mn	Cd	Cr	Cu	Ni	Pb	Zn	Hg
					μg/g					
Aurora	4014	320	12	0.21	267	21	3.3	11.3	19	0.07
Midland	1165	542	18	0.19	62	18	108.4	26.6	70	0.34
Pt. Edward	563	22310	67	1.1	12.6	126	4.9	164.9	144	0.32
Sarnia	401	5154	171	4.89	6.5	38	2.1	226.8	795	0.19
Guelph	2068	940	9	7.99	129	106	3.8	47.0	244	0.39
Fergus	207	555	10	0.94	113	259	7.0	14.6	384	0.10
North Toronto	964	5628	22	2.16	37	104	2.3	138.8	216	1.64
Newmarket	499	867	29	0.15	5.1	21	3.7	16.2	57	0.26
Toronto Humber	980	2541	26	9.37	265	116	44.6	214.2	552	0.55

TABLE 165. Concentration of Various Constituents in Third Application of Nine Ontario Fluid Sewage Sludges used in 1974 Greenhouse Experiments.

Sludge	pH	DM %	N %	Available N µg/g	P %	K %	Ca %	Mg %	Na %	B µg/g
Aurora	6.9	1.9	.08	50	0.04	.003	0.11	.02	.03	5
Midland	7.1	7.0	.08	100	0.25	.01	2.04	.10	.01	9
Pt. Edward	7.1	6.4	.18	510	0.27	.01	0.41	.05	.01	3
Sarnia	7.2	13.1	.34	580	0.27	.04	0.63	.16	.01	5
Guelph	7.2	2.4	.14	610	0.40	.01	0.20	.04	.02	3
Fergus	7.3	2.5	.18	800	0.06	.01	0.17	.04	.04	3
North Toronto	7.2	5.4	.33	830	0.22	.02	0.30	.05	.01	4
Newmarket	7.1	10.0	.17	290	0.17	.01	4.39	.07	.01	5
Toronto Humber	7.3	3.9	.21	710	0.10	.01	0.28	.04	.01	4

TABLE 166. Metal Concentration in Third Application of Nine Ontario Fluid Sewage Sludges used in 1974 Greenhouse Experiments.

Sludge	Al	Fe	Mn	Cd	Cr	Cu	Ni	Pb	Zn	Hg	Se	Mo
						ug/g						
Aurora	2113	128	3.0	0.04	188	8.7	0.7	4.5	6.8	.03	1.68	0.19
Midland	680	579	19.5	0.63	53	27.6	3380	26.3	101.8	.34	0.96	0.42
Pt. Edward	170	9338	24.3	0.56	4	61.8	1.6	53.9	68.9	.18	0.00	0.47
Sarnia	753	11593	34.1	11.40	12	104.8	3.3	406.1	1389.9	1.00	0.00	1.38
Guelph	722	625	5.8	5.00	83	69.6	1.9	34.2	161.7	.17	3.84	1.76
Fergus	74	1692	5.7	0.47	20	106.8	5.1	16.7	395.2	.07	0.04	0.23
North Toronto	745	4526	25.2	2.02	32	84.0	1.5	109.8	140.9	1.27	0.08	1.25
Newmarket	189	474	32.4	0.50	2	21.9	1.2	14.0	61.8	.21	1.96	0.57
Toronto Humber	462	1330	12.0	6.21	214	59.5	19.8	180.5	334.9	.51	3.68	4.40

TABLE 167. Total Amounts of Various Constituents Supplied by the First Two Additions of Nine Ontario Sludges at 200 kg N/ha rate per addition in the Greenhouse.

Treatment Plant	Solids	Nitrogen Total	(Available)	P	K	Ca	Mg	Na	B
		kg/ha*							
Aurora	10,070	400	120	260	23	720	50	60	0.7
Midland	22,510	400	70	870	36	3120	190	38	1.1
Point Edward	18,220	400	70	680	33	1740	140	18	0.2
Sarnia	11,940	400	160	411	49	540	150	20	0.3
Guelph	10,760	400	190	354	24	640	80	42	0.3
Fergus	6,970	400	190	132	27	420	100	92	0.2
North Toronto	9,340	400	140	422	29	380	60	23	0.2
Newmarket	28,420	400	170	279	39	6370	140	45	0.3
Toronto Humber	8,050	400	190	246	33	420	60	28	0.2

* Data presented in kg/ha. If the nitrogen application is taken as 200 lb/acre (instead of 200 kg/ha) all other data in the table can be read as lb/acre.

TABLE 168. Total Amounts of Metals Supplied by the First Two Additions of Nine Ontario Sludges at 200 kg N/ha rate per Addition in the Greenhouse.

Treatment Plant	Al	Mn	Fe	Cd	Cr	Cu	Ni	Pb	Zn	Hg
				kg/ha*						
Aurora	930	2.6	74	.08	81.9	4.6	1.1	2.9	4.3	.02
Midland	450	8.1	280	.20	34.3	10.8	90.6	22.4	32.6	.15
Point Edward	66	7.2	1548	.09	0.9	12.1	0.4	15.7	14.0	.03
Sarnia	77	35.7	1018	1.07	1.3	8.3	0.4	45.5	161.0	.05
Guelph	226	2.2	230	2.11	35.3	27.9	1.0	12.5	68.4	.09
Fergus	31	2.0	100	0.34	34.0	50.5	1.0	2.8	86.6	.02
North Toronto	120	3.3	770	.32	5.8	13.4	0.4	17.6	30.0	.19
Newmarket	130	8.7	200	.07	0.9	6.0	0.6	3.9	15.6	.06
Toronto Humber	95	2.9	280	1.11	28.0	12.9	4.8	14.3	57.2	.06

* Data presented in kg/ha. If the nitrogen application is taken as 200 lb/acre (instead of 200 kg/ha) all other data in the table can be read as lb/acre

TABLE 169. Dry Matter Yield or Ryegrass g/pot (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
			DRY MATTER - g/pot			
NONE	6.0	9.5				7.8
AURORA	9.9	10.4	9.8	10.4	10.1	10.1
MIDLAND	10.6	10.8	7.7	10.8	12.2	10.2
POINT EDWARD	10.0	10.2	8.6	12.3	9.8	10.2
SARNIA	10.0	12.4	8.1	10.9	12.9	10.6
GUELPH	8.5	8.9	9.6	10.8	7.1	9.2
FERGUS	4.4	6.9	9.1	4.7	4.4	6.1
NORTH TORONTO	9.8	11.1	9.7	11.1	10.5	10.4
NEWMARKET	8.7	10.2	11.2	11.0	7.8	10.0
TORONTO HUMBER	8.6	11.3	10.9	9.7	9.6	10.1
MEAN	8.6	10.2	9.4	10.2	9.4	9.4

Significance of "F" Test

sludge source - 0.01
sludge rate - 0.05
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.05
soil pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 170. Dry Matter Yield of Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	Nitrogen Rate lb/ac (kg/ha)				Mean
	178(200)	712(800)	1424(1600)	1424(1600) **	
			g/pot		
None					7.4
Aurora	7.3	6.0	4.5	6.0	5.9
Midland	6.8	7.7	6.5	6.5	6.9
Pt. Edward	6.4	4.8	2.5	4.2	4.5
Sarnia	7.8	5.2	4.5	5.5	5.9
Guelph	7.7	5.0	2.9	4.2	4.9
Fergus	7.5	3.9	2.6	3.0	4.3
N. Toronto	7.5	7.7	5.7	7.3	7.0
Newmarket	6.8	5.6	2.0	4.0	4.6
Tor. Humber	8.3	7.2	4.3	5.3	6.3
Mean	7.3	6.0	3.9	5.1	5.6
pH 5.0	7.6	6.5	4.1	5.2	5.8
7.0	7.1	5.5	3.8	5.0	5.3

Significance of "F" test at 0.05 and 0.01 probability.

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	soil pH x rate	- 0.05
soil pH	- 0.01	soil pH x source	- N.S.

* One Application

TABLE 171. Electrical Conductivity of Saturated Soil Extract from Greenhouse Experiment 1. Following Third Sludge Application at 1600 Kg N/ha, 1975.

Sludge	Electrical Conductivity µmhos/cm^3		
	soil pH 5.0	soil pH 7.0	Mean
None	900	850	875
Aurora	2900	4700	3800
Midland	2000	2300	2150
Point Edward	4300	3000	3650
Sarnia	3900	4900	4400
Guelph	10000	7000	8500
Fergus	9500	13000	11250
North Toronto	4800	4500	4650
Newmarket	5600	7000	6300
Toronto Humber	7500	5500	6500

TABLE 172. pH Values of Soil, After Second Crop of Ryegrass. Greenhouse Experiment 1, 1974.

Sludge	ORIGINAL SOIL pH 5.0 Nitrogen Rate (kg/ha) 200	800	1600	1600*	Mean	ORIGINAL SOIL pH 7.0 Nitrogen Rate (kg/ha) 200	800	1600	1600*	Mean
None					4.6					6.0
Aurora	5.4	6.2	6.5	6.2	6.1	6.7	7.0	7.0	7.0	6.9
Midland	6.4	7.2	7.5	6.7	7.0	7.0	7.4	7.5	7.0	7.2
Point Edward	6.0	6.7	6.9	6.9	6.6	6.8	7.1	7.1	6.9	7.0
Sarnia	5.4	6.0	6.0	5.7	5.8	6.5	6.3	6.2	6.2	6.3
Guelph	4.9	5.3	5.6	5.0	5.2	6.5	5.9	6.1	5.6	6.0
Fergus	4.9	5.0	5.5	4.8	5.0	6.3	5.4	5.2	5.4	5.6
North Toronto	4.8	4.5	4.6	4.8	4.7	6.2	5.7	5.3	5.7	5.7
Newmarket	7.1	7.5	7.7	7.4	7.4	7.7	7.8	7.7	7.7	7.7
Toronto Humber	5.0	4.8	4.7	4.7	4.8	6.4	5.8	5.3	5.7	5.8

*One application

TABLE 173. Nitrogen Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
			NITROGEN CONCENTRATION - %			
NONE	1.60	1.98				1.79
AURORA	3.59	3.37	2.28 a	3.14 bcd	4.60 fgh	3.34
MIDLAND	3.30	3.59	2.31 a	2.70 b	4.36 efg	3.12
POINT EDWARD	3.99	4.13	3.11 bcd	3.66 de	4.72 fgh	3.83
SARNIA	4.13	4.16	3.28 cd	4.40 fgh	4.45 fgh	4.04
GUELPH	4.18	4.48	3.64 de	4.58 fgh	4.55 fgh	4.26
FERGUS	3.99	4.57	3.50 d	4.51 fgh	4.57 fgh	4.19
NORTH TORONTO	3.92	4.08	2.85 bc	4.10 ef	4.52 fgh	3.82
NEWMARKET	4.39	4.13	3.26 cd	4.39 fgh	4.69 gh	4.11
TORONTO HUMBER	4.20	4.31	3.26 cd	4.71 gh	4.52 fgh	4.16
MEAN	3.73	3.92	3.05	4.02	4.55	3.87

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.05
soil pH x rate - 0.01
source x rate x soil pH - N.S.

TABLE 174. Nitrogen Concentration in Ryegrass. Second Crop, Greenhouse Experiment 2, 1974.

Nitrogen Rate lb/ac (kg/ha)	pH 5.0	pH 7.0	Mean
	% N		
Control	4.6	4.9	4.8
178 (200)	4.1	4.4	4.2
712 (800)	5.1	5.1	5.1
1424 (1600)	5.2	5.1	5.2
1424 one (1600) application	5.1	5.0	5.1

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - N.S.

sludge rate - 0.01

soil pH - N.S.

soil pH x rate - 0.01

TABLE 175. Phosphorus Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
	PHOSPHORUS CONCENTRATION - %					
NONE	0.59	0.62				0.60
AURORA	0.66	0.65	0.70	0.72	0.61	0.68
MIDLAND	0.72	0.72	0.70	0.76	0.71	0.72
POINT EDWARD	0.71	0.71	0.79	0.76	0.65	0.73
SARNIA	0.68	0.70	0.70	0.70	0.69	0.70
GUELPH	0.72	0.73	0.76	0.75	0.70	0.74
FERGUS	0.57	0.67	0.72	0.54	0.62	0.63
NORTH TORONTO	0.73	0.69	0.76	0.71	0.68	0.72
NEWMARKET	0.70	0.60	0.69	0.57	0.67	0.64
TORONTO HUMBER	0.70	0.71	0.71	0.70	0.71	0.71
MEAN	0.68	0.68	0.72	0.69	0.67	0.69

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - N.S.

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - N.S.
source x rate x soil pH - 0.05

TABLE 176. Phosphorus Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974

Sludge	Mean	Nitrogen Rate lb/ac (kg/ha)	Mean
	P - %		P - %
None	0.74	200 (224)*	0.74
Aurora	0.69	178 (200)	0.80
Midland	0.80	712 (800)	0.74
Point Edward	0.74	1424 (1600)	0.71
Sarnia	0.75	1424 (1600)**	0.75
Guelph	0.77		
Fergus	0.78		
North Toronto	0.76		
Newmarket	0.71		
Toronto Humber	0.77		
Mean	0.75		

*NH_4NO_3

**One application

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01 soil pH x rate - 0.05

sludge rate - 0.01

soil pH - N.S.

TABLE 177. Potassium Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
	POTASSIUM CONCENTRATION - %					
NONE	4.61	4.76				4.68
AURORA	6.25	6.37	5.40	5.93	6.90	6.08
MIDLAND	5.91	6.23	5.62	5.74	6.45	6.08
POINT EDWARD	6.20	6.12	6.04	6.06	6.27	6.12
SARNIA	6.30	6.24	6.14	6.39	6.28	6.27
GUELPH	6.00	6.44	6.30	6.71	5.94	6.32
FERGUS	5.87	6.70	6.59	6.07	6.24	6.30
NORTH TORONTO	6.65	6.50	6.11	6.69	6.74	6.51
NEWMARKET	6.42	6.18	5.91	6.16	6.57	6.21
TORONTO HUMBER	6.39	6.29	5.63	6.70	6.51	6.28
MEAN	6.06	6.18	5.97	6.27	6.43	6.22

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.05

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 178. Potassium Concentration in Ryegrass. Second Crop, Greenhouse Experiment, 1974.

Sludge	Mean
	K - %
None	6.4
Aurora	6.7
Midland	6.1
Point Edward	6.1
Sarnia	6.2
Guelph	6.1
Fergus	6.6
North Toronto	6.3
Newmarket	6.4
Toronto Humber	6.4
Mean	6.3

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01 soil pH x rate - N.S.

sludge rate - 0.01

soil pH - 0.05

TABLE 179. Calcium Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
			CALCIUM CONCENTRATION - %			
NONE	0.47	0.68				0.58
AURORA	0.70	0.84	0.66	0.72	0.86	0.75
MIDLAND	0.72	0.81	0.66	0.67	0.86	0.73
POINT EDWARD	0.96	0.99	0.77	0.88	1.14	0.93
SARNIA	0.82	0.92	0.70	0.90	0.91	0.84
GUELPH	0.90	1.16	0.81	0.98	1.05	0.95
FERGUS	0.71	0.99	0.73	0.91	0.87	0.84
NORTH TORONTO	0.72	0.99	0.68	0.88	0.91	0.82
NEWMARKET	1.02	1.07	0.84	1.05	1.09	0.99
TORONTO HUMBER	0.81	1.08	0.70	0.92	1.04	0.89
MEAN	0.78	0.95	0.73	0.88	0.97	0.86

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.05
source x soil pH - 0.01
source pH x rate - 0.01
source x rate x soil pH - N.S.

TABLE 180. Calcium Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	Nitrogen Rate lb/ac (kg/ha) 178(200)	712(800)	1424(1600)	1424(1600) (1 application)	Mean
	Ca - %				
None					0.7
Aurora	0.8	1.2	1.2	1.1	1.1
Midland	0.9	1.1	1.1	1.1	1.0
Pt. Edward	1.0	1.6	1.7	1.6	1.5
Sarnia	0.9	1.1	1.0	1.0	1.0
Guelph	0.9	1.1	1.1	1.1	1.1
Fergus	0.8	0.8	0.8	0.9	0.8
N. Toronto	0.7	0.9	0.8	1.0	0.9
Newmarket	1.1	1.6	1.5	1.4	1.4
Tor. Humber	0.8	0.9	0.9	1.0	0.9
Mean	0.9	1.1	1.1	1.1	1.1
pH 5.0	0.7	0.9	1.0	1.0	0.9
7.0	1.0	1.3	1.2	1.2	1.2

Significance of "F" test at 0.05 and 0.01 probability.

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	soil pH x rate	- N.S.
soil pH	- 0.01	soil pH x source	- 0.01

TABLE 181. Magnesium Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
			MAGNESIUM CONCENTRATION - %			
NONE	0.13	0.13				0.13
AURORA	0.27	0.25	0.17	0.22	0.33	0.24
MIDLAND	0.26	0.25	0.16	0.19	0.33	0.23
POINT EDWARD	0.27	0.24	0.19	0.21	0.32	0.24
SARNIA	0.31	0.28	0.20	0.30	0.33	0.28
GUELPH	0.27	0.28	0.21	0.30	0.29	0.27
FERGUS	0.23	0.28	0.21	0.28	0.27	0.25
NORTH TORONTO	0.26	0.25	0.16	0.27	0.29	0.24
NEWMARKET	0.26	0.23	0.18	0.25	0.28	0.24
TORONTO HUMBER	0.27	0.26	0.17	0.30	0.30	0.26
MEAN	0.25	0.24	0.18	0.26	0.31	0.25

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 182. Magnesium Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974

Sludge	pH		Mean	Nitrogen Rate lb/ac (kg/ha)	Mean
	5.0	7.0			
		Mg-%			Mg-%
None	0.27	0.27	0.27	200 (224)*	0.27
Aurora	0.37	0.33	0.36	178 (200)	0.31
Midland	0.41	0.38	0.40	712 (800)	0.37
Point Edward	0.51	0.31	0.41	1424 (1600)	0.33
Sarnia	0.38	0.39	0.39	1424 (1600)**	0.35
Guelph	0.32	0.34	0.33		
Fergus	0.29	0.30	0.30		
North Toronto	0.31	0.34	0.33		
Newmarket	0.29	0.22	0.26		
Toronto Humber	0.29	0.29	0.29		
Mean	0.35	0.32	0.34		

*NH_4NO_3

**One application

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01

sludge rate - N.S.

soil pH - 0.05

soil pH x rate - N.S.

source x pH - 0.05

TABLE 183. Boron Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
			BORON CONCENTRATION - µg/g			
NONE	12.5	7.5				10.0
AURORA	12.3	6.9	8.3	10.5	9.8	9.5
MIDLAND	35.6	19.8	13.0	33.8	32.0	26.3
POINT EDWARD	10.9	8.9	7.8	7.0	12.4	9.1
SARNIA	16.9	12.8	8.5	11.8	19.5	13.3
GUELPH	11.8	12.1	8.8	10.0	14.5	11.1
FERGUS	10.1	9.9	7.3	9.9	11.4	9.5
NORTH TORONTO	9.3	6.3	8.3	8.0	7.4	7.9
NEWMARKET	6.5	5.0	6.5	6.0	5.3	5.9
TORONTO HUMBER	10.3	12.4	7.8	7.8	14.9	10.2
MEAN	13.6	10.2	8.5	11.6	14.1	11.4

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
source pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 184. Cadmium Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	NITROGEN lb/ac (kg/ha)							
	pH 5.0				pH 7.0			
	178 (200)	712 (800)	1424 (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	MEAN
	CADMIUM CONCENTRATION - µg/g							
NONE				0.37				0.55
AURORA	0.56	0.58	0.77	0.64	0.63	0.60	0.75	0.66
MIDLAND	0.45	0.50	0.63	0.53	0.55	0.45	0.66	0.55
POINT EDWARD	0.58	0.55	0.66	0.59	0.85	0.60	0.56	0.67
SARNIA	0.70	1.15	1.44	1.09	0.65	1.00	1.07	0.91
GUELPH	1.30	2.52	4.31	2.71	1.03	2.15	2.30	1.83
FERGUS	0.60	1.79	1.74	1.38	0.73	1.18	0.95	0.95
NORTH TORONTO	0.48	0.63	0.64	0.58	0.70	0.70	0.82	0.74
NEWMARKET	0.65	0.70	0.60	0.65	0.62	0.55	0.65	0.61
TORONTO HUMBER	0.62	1.13	2.47	1.41	0.90	1.60	1.94	1.48
MEAN	0.66	1.06	1.47	1.06	0.74	0.98	1.08	0.93

Significance of "F" test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x rate x soil pH - 0.01

TABLE 185. Cadmium Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974

Sludge	Mean	Nitrogen Rate lb/ac (kg/ha)	Mean
	Cd ug/g		Cd ug/g
None	0.36	200 (224)*	0.36
Aurora	0.60	178 (200)	0.50
Midland	0.32	712 (800)	0.80
Point Edward	0.40	1424 (1600)	0.91
Sarnia	0.69	1424 (1600)**	0.98
Guelph	2.30		
Fergus	0.98		
North Toronto	0.33		
Newmarket	0.55		
Toronto Humber	1.01		
Mean	0.80		

*NH_4NO_3

**One application

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01

sludge rate - 0.05

soil pH - N.S.

soil pH x rate - N.S.

TABLE 186. Chromium Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
	CHROMIUM CONCENTRATION - µg/g					
NONE	1.2	1.5				1.4
AURORA	1.8	1.8	1.7	2.0	1.7	1.8
MIDLAND	2.0	1.6	1.9	1.6	1.9	1.8
POINT EDWARD	1.7	2.4	2.1	2.1	2.0	2.1
SARNIA	1.8	2.1	2.0	2.0	1.9	2.0
GUELPH	2.2	2.1	2.1	2.5	2.0	2.2
FERGUS	1.9	2.6	2.5	1.9	2.3	2.2
NORTH TORONTO	2.2	2.2	2.2	2.6	2.0	2.3
NEWMARKET	1.8	2.1	2.0	2.0	1.8	1.9
TORONTO HUMBER	1.9	1.8	1.8	1.9	1.9	1.8
MEAN	1.3	2.0	2.0	2.1	2.0	2.0

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - N.S.
soil pH - 0.05
source x rate - N.S.
source x soil pH - 0.01
soil pH x rate - 0.05
source x rate x soil pH - 0.05

TABLE 187. Chromium Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	Mean	Nitrogen Rate lb/ac (kg/ha)	Mean
	Cr ug/g		Cr ug/g
None	0.9	200 (224)*	0.9
Aurora	1.7	178 (200)	0.9
Midland	1.1	712 (800)	1.0
Point Edward	1.1	1424 (1600)	1.2
Sarnia	0.9	1424 (1600)**	1.2
Guelph	1.2		
Fergus	1.1		
North Toronto	0.8		
Newmarket	0.9		
Toronto Humber	0.8		
Mean	1.1		

*NH_4NO_3

**One application

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01 soil pH x rate - N.S.

sludge rate - N.S.

soil pH - N.S.

TABLE 188. Copper Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
	COPPER CONCENTRATION - µg/g					
NONE	10	10				10
AURORA	15	15	11	14	17	14
MIDLAND	14	14	11	14	16	14
POINT EDWARD	18	17	14	16	20	17
SARNIA	18	18	14	19	20	18
GUELPH	22	19	18	20	22	20
FERGUS	21	20	15	21	22	20
NORTH TORONTO	16	16	12	16	18	15
NEWMARKET	16	16	13	16	17	15
TORONTO HUMBER	19	17	12	18	20	17
MEAN	17	16	13	17	19	17

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - N.S.
source x soil pH - N.S.
soil pH x rate - 0.01
source x rate x soil pH - N.S.

TABLE 189. Copper Concentration of Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	Mean	Nitrogen Rate lb/ac (kg/ha)	Mean
	Cu ug/g		Cu ug/g
None	18.3	200 (224)*	18.3
Aurora	20.3	178 (200)	22.7
Midland	21.2	712 (800)	27.5
Point Edward	37.5	1424 (1600)	30.7
Sarnia	29.6	1424 (1600)**	30.5
Guelph	29.3		
Fergus	33.3		
North Toronto	26.9		
Newmarket	24.9		
Toronto Humber	27.9		
Mean	27.9		

*NH_4NO_3

**One application

Significance of "F" test at 0.05 and 0.01 probabilities.

sludge source - .01

sludge rate - .01

soil pH - N.S.

soil pH x rate - N.S.

source x rate - N.S.

TABLE 190. Iron Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
	IRON CONCENTRATION - µg/g					
NONE	91	121				
AURORA	105	137	106	145	117	123
MIDLAND	85	101	90	86	98	91
POINT EDWARD	116	141	124	90	151	122
SARNIA	113	110	116	106	112	111
GUELPH	109	119	121	126	105	117
FERGUS	118	114	120	123	111	118
NORTH TORONTO	105	118	98	109	120	109
NEWMARKET	115	123	134	126	109	123
TORONTO HUMBER	107	113	104	109	114	109
MEAN	106	119	113	113	115	114

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - N.S.
soil pH - 0.01

source x rate - 0.01
source x soil pH - N.S.
soil pH x rate - 0.01
source x rate x soil pH - N.S.

TABLE 191. Iron Concentration of Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	Mean	Nitrogen Rate lb/ac (kg/ha)	Mean
	Fe ug/g		Fe ug/g
None	190	Control	190
Aurora	220	178 (200)	200
Midland	184	712 (800)	205
Point Edward	239	1424 (1600)	281
Sarnia	213	1424 (1600)*	254
Guelph	303	Mean	235
Fergus	278		
North Toronto	203		
Newmarket	238		
Toronto Humber	235		
Mean	235		

*One application

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01 soil pH x rate - N.S.

sludge rate - 0.01 source x rate - N.S.

soil pH - N.S.

TABLE 192. Manganese Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	SOIL pH		NITROGEN lb/ac (kg/ha)			
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	MEAN
	MANGANESE CONCENTRATION - µg/g					
NONE	432	208				320
AURORA	665	254	245	614	490	449
MIDLAND	254	184	230	215	215	220
POINT EDWARD	185	148	223	153	145	174
SARNIA	464	273	338	374	381	364
GUELPH	672	253	322	523	503	449
FERGUS	652	319	393	570	490	484
NORTH TORONTO	538	245	298	370	449	372
NEWMARKET	207	170	203	208	172	194
TORONTO HUMBER	611	253	324	423	490	412
MEAN	468	230	286	383	370	346

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x rate x soil pH - 0.01

TABLE 193. Manganese Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974

Sludge	Mean	Nitrogen Rate lb/ac (kg/ha)	pH 5.0	pH 7.0	Mean
		Mn ug/g			
None	605	200 (224)*	1081	123	605
Aurora	240	178 (200)	451	142	296
Midland	167	712 (800)	436	189	312
Point Edward	132	1424 (1600)	288	260	274
Sarnia	391	1424 (1600)**	555	235	395
Guelph	489				
Fergus	552				
North Toronto	384				
Newmarket	175				
Toronto Humber	345				
Mean	319		432	207	319

*NH_4NO_3

**One application

Significance of "F" test at 0.05 and 0.01 probability.

sludge source	- 0.01	soil pH x rate	- 0.01
sludge rate	- 0.01	sludge source x pH	- 0.05
soil pH	- 0.01		

TABLE 194. Nickel Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	NITROGEN lb/ac (kg/ha)							
	pH 5.0				pH 7.0			
	178 (200)	712 (800)	1424 (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	MEAN
	NICKEL CONCENTRATION - µg/g							
NONE				4.3				2.0
AURORA	4.3	3.4	2.8	3.5	3.3	4.0	2.5	3.3
MIDLAND	34.5	46.5	61.5	47.5	8.5	32.0	33.1	24.5
POINT EDWARD	3.5	2.8	1.8	2.7	2.5	2.3	2.8	2.5
SARNIA	4.8	4.0	4.3	4.4	3.5	2.5	2.5	2.8
GUELPH	4.5	8.0	11.5	8.0	3.5	5.0	4.6	4.4
FERGUS	4.8	7.4	7.4	6.5	2.0	3.8	3.5	3.1
NORTH TORONTO	5.0	5.0	6.5	5.5	3.5	4.0	4.1	3.9
NEWMARKET	3.0	2.0	1.6	2.2	2.3	2.3	2.1	2.2
TORONTO HUMBER	6.8	17.5	26.8	17.0	2.0	5.3	12.1	6.5
MEAN	7.9	10.7	13.8	10.8	3.4	6.8	7.5	5.9

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x rate x soil pH - 0.01

TABLE 195. Nickel Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	pH		Nitrogen Rate lb/ac (kg/ha)				Mean
	5.0	7.0	178(200)	712(800)	1424(1600)	1424(1600) (1 application)	
				Ni - µg/g			
None	3.6	1.7					2.7
Aurora	1.4	1.0	1.6	0.7	0.9	1.5	1.2
Midland	39.7	32.8	16.6	34.9	44.8	48.7	36.2
Pt. Edward	0.9	0.9	1.2	0.5	0.7	1.0	0.9
Sarnia	2.3	1.3	2.2	1.6	1.7	1.7	1.8
Guelph	5.4	1.5	3.2	3.5	2.4	4.6	3.4
Fergus	7.8	4.6	4.6	6.6	7.1	6.6	6.2
N. Toronto	4.1	1.5	2.5	2.6	2.1	4.0	2.8
Newmarket	1.3	1.5	1.3	1.2	1.6	1.4	1.4
Tor. Humber	22.3	8.6	9.4	15.4	17.2	19.7	15.7
Mean	9.5	6.0	4.7	7.5	8.7	9.9	7.7
pH 5.0			6.6	8.3	9.8	13.1	9.5
7.0			2.9	6.6	7.7	6.7	6.0

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01	source x rate - 0.01
sludge rate - 0.01	soil pH x rate - 0.01
soil pH - 0.01	soil pH x source - 0.01

TABLE 196. Zinc Concentration in Ryegrass (Greenhouse, 1974, first crop).

SLUDGE	NITROGEN lb/ac (kg/ha)							
	pH 5.0				pH 7.0			
	178 (200)	712 (800)	1424 (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	MEAN
	ZINC CONCENTRATION - μg/g							
NONE				60				42
AURORA	48	40	50	46	35	28	31	31
MIDLAND	42	33	43	40	36	30	32	32
POINT EDWARD	54	47	50	50	34	34	42	37
SARNIA	156	311	400	289	59	166	238	154
GUELPH	130	239	420	263	64	67	47	59
FERGUS	52	43	43	46	35	46	68	49
NORTH TORONTO	84	131	147	121	52	64	73	63
NEWMARKET	60	48	58	55	34	39	50	41
TORONTO HUMBER	102	256	371	243	47	90	145	94
MEAN	81	128	176	128	44	62	81	62

Significance of "F" test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x soil pH x rate - 0.01

TABLE 197. Zinc Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	ORIGINAL SOIL pH									
	5.0					7.0				
	Nitrogen Rate lb/ac (kg/ha)					Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Zn µg/g									
None					86					38
Aurora	57	50	47	54	52	29	38	41	42	37
Midland	46	44	57	57	51	29	42	45	41	39
Point Edward	59	45	54	37	49	33	38	47	56	44
Sarnia	200	207	200	272	220	105	218	211	225	190
Guelph	111	143	109	226	148	58	133	112	133	109
Fergus	190	220	201	500	278	65	196	185	179	156
North Toronto	100	109	106	121	109	37	66	81	76	65
Newmarket	38	47	68	51	51	25	47	78	49	49
Toronto Humber	117	152	132	215	170	49	107	102	103	90
Mean	102	113	108	170	123	48	98	100	100	87

*One application

Significance of "F" test at 0.05 and 0.01 probabilities -

sludge source	.01	soil pH x rate	.01	soil pH x rate x source	.01
sludge rate	.01	source x rate	.01		
soil pH	.01	soil pH x source	.01		

TABLE 198. Zinc Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	Nitrogen Rate lb/ac (kg/ha) 178 (200)	 712 (800)	 1424 (1600)	 1424* (1600)	Mean
			Zn µg/g		
None					62
Aurora	43	44	44	48	45
Midland	37	43	51	49	45
Point Edward	46	42	51	47	46
Sarnia	152	213	206	249	205
Guelph	85	138	111	180	128
Fergus	127	208	193	340	217
North Toronto	69	87	93	99	87
Newmarket	31	47	73	50	50
Toronto Humber	83	130	117	159	122
Mean	74	106	104	135	105

*One application.

Significance of "F" test at 0.05 and 0.01 probabilities.

sludge source	.01	soil pH x rate	.01	soil pH x rate x source	.01
sludge rate	.01	source x rate	.01		
soil pH	.01	soil pH x source	.01		

TABLE 199. Concentration of Al and Pb in Ryegrass as Affected by Various Sludges. (Greenhouse, 1974, first crop)

SLUDGE	ALUMINUM µg/g	LEAD µg/g
NONE	36	5.0
AURORA	36	3.7
MIDLAND	25	4.0
POINT EDWARD	32	4.2
SARNIA	30	4.1
GUELPH	36	4.5
FERGUS	37	3.5
NORTH TORONTO	34	3.4
NEWMARKET	32	5.2
TORONTO HUMBER	39	5.4

STATISTICAL SIGNIFICANCE AT PROBABILITY LEVELS LISTED		
FACTOR	Al	Pb
SLUDGES	.05	.01
RATE	N.S.	N.S.
SOIL pH	N.S.	N.S.
SLUDGE X RATE	N.S.	N.S.
SLUDGE X pH	N.S.	N.S.
SOIL pH X RATE	N.S.	N.S.
SOURCE X RATE X pH	.05	N.S.

TABLE 200. Aluminum Concentration in Ryegrass. Second Crop, Greenhouse Experiment 1, 1974.

Sludge	Mean	Nitrogen Rate lb/ac (kg/ha)	Mean
	Al μg/g		Al μg/g
None	126	200 (224)*	126
Aurora	155	178 (200)	96
Midland	107	712 (800)	114
Point Edward	142	1424 (1600)	173
Sarnia	116	1424 (1600)**	150
Guelph	177		
Fergus	162		
North Toronto	99		
Newmarket	113		
Toronto Humber	125		
Mean	133		

*NH_4NO_3

**One application

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.05 soil pH x rate - N.S.

sludge rate - 0.01

soil pH - N.S.

TABLE 201. Average Value, Ranges and Median Value of Soil and Plant Variables. Greenhouse Experiment 2.

Variable	Minimum	Maximum	Mean	Median
			Soil	
pH	4.3	7.9	6.8	6.9
Cation Exchange Capacity	5.4	67.4	28.5	23.9
Organic Matter %	0.6	16.9	4.5	3.3
Clay %	2.7	53.9	18.1	13.2
			Plant	
D.M. yield-gm/pot	7.9	21.3	13.9	13.7
Cu-µg/g	7.0	60.0	20.1	16.3
Zn-µg/g	29.0	3250.0	331.0	89.0
Cd-µg/g	0.01	51.9	3.66	0.93
Ni-µg/g	0.01	132.76	8.15	2.0
Pb-µg/g	2.5	11.0	4.7	4.5

TABLE 202. Soil Extractants Used in Greenhouse Experiment 2.

Extractant	Chemicals	pH	Soil:Solution Ratio	Shaking Time	Reference
EDTA	0.01 M EDTA 1.0 M $(NH_4)_2CO_3$	8.6	1:2	30 min	Trierweiler & Lindsay
DTPA	0.05 M DTPA 0.1 M TEA 0.01 M $CaCl_2$	7.3	1:2	2 hr	Linday & Norvall
Acetic acid	0.05 N CH_3COOH		1:20	2 hr	Scott & Mitchell
Aqua Regia	18 ml HCl/g soil 6 ml HNO_3/g soil		1:24	30 min digestion	Van Loon & Lichwa
	after digestion samples were diluted and filtered to final volume of 25 ml				
Water	H_2O		1:2		
	solution concentrated using organic solvent (MIBK)				

7 SOIL CHARACTERIZATION

7.1 First Greenhouse Study

7.1.1 Objectives

To evaluate soil structure produced by the addition of sewage sludge. To determine the ultimate location of heavy metals in soils after additions of various sludges.

7.1.2 Methods and materials

Bulk soil samples from a check and the 5000 kg N/ha treatment of each sludge at both pH values were taken for chemical analysis.

Blocks the full depth of the soils, extending to the centre from one edge of the pot and about two inches wide were sampled for thin sections.

The sludges reacted with vestapol, so cast-embed was used as the impregnating resin. The resin did not harden at one atmosphere pressure so the blocks were subjected to fifteen atmospheres pressure with additional hardener dropped on the surface. Following this treatment the resin hardened in two hours. Thin sections were then prepared in the routine manner.

Sodium-dithionite and NH_4-oxalate extractable Fe, Al and Mn were determined as described by Raad, Protz and Thomas (1969). Sodium-dithionite extractable Ca, Mg and NH_4-oxalate extractable Mg were determined as outlined by Raad (1969). Sodium-dithionite extractable Zn was determined using the method outlined by Jenne, Ball and Simpson (1974).

The electron microprobe analyses were done on specially cut thin sections. These sections were carbon coated using standard high vacuum techniques and examined in an Acton electron microprobe at the University of Waterloo. The microprobe was fitted with an extra light source which allowed observation of the specimen by plain transmitted light during analyses, thus allowing accurate identification of features.

7.1.3 Results and discussion

Each of the three sludges possessed distinctive micromorphological forms in the soils. None of the features described here are similar to natural features as described by Protz, 1974 or in Section 7.3.3 of this report.

The Ca-sludge was a grainy white precipitate (Figure 1a) -- a mixture of Ca, P and Si (Figure 2). Some of the Ca was segregated into nearly "pure" Ca compounds (Figure 1a), presumably $CaCO_3$. These were usually on the edges of sludge beds and ranged in size from 40 to 150 μ.

Under the petrographic microscope Al-sludge appeared to have narrow slivers or fibres of crystalline compounds (Figure 1b). However, under the electron microprobe (after high vacuum treatment during carbon coating) these slivers have not yet been adequately identified. Narrow concentrations of Al parallel to the slivers were found but it cannot be definitely stated that these are or are not Al compounds (Figure 3). These slivers ranged in width from 5 to 30 μ and in length from 30 to 400 μ.

Under the petrographic microscope some Fe concentrations appeared amorphous and a few were crystalline (Figure 1c). The Fe-sludge had concentrations of Fe - P minerals (Figure 4). The concentrations of Fe ranged in size from 5 to 40 μ.

There was an increase of Na-dithionite extractable Fe (Table 203) from the clay loam and sandy loam soils treated with Fe-sludge. The NH_4-oxalate extractable Fe was higher than the check only for the sandy loam soil treated with Fe-sludge. This confirmed the microprobe data (Figure 4) that the Fe in the Fe-sludge was in crystalline form, not an organic matter chelate. The Na-dithionite extractable Al was equal to the checks, whereas the NH_4-oxalate extractable Al was higher in the Al-sludge treated soils than in the checks (Table 203). This indicates that the Al from the sludge may be chelated to organic matter and not in inorganic crystals.

The Na-dithionite extractable Ca was, as expected, higher for all samples in which the pH was raised to 7.5 (Table 204). The soils treated with Ca-sludge had higher Na-dithionite extractable Ca than did the checks (Table 204). NH_4-oxalate extractable Mg was higher in the soils treated with Ca-sludge (Table 204). The Na-dithionite extractable Zn levels were uniformly low.

Also, concentrations of heavy metals were not found in any of the thin sections studied. Since low concentrations of heavy metals were found in these three sludges (Volume II for this project, FY 73/74), it is unlikely that concentrations could form during the short duration of the greenhouse experiment.

7.1.4 Conclusions

The material in sludges has been segregated into various compounds. It is possible that this segregation of compounds could have occurred during the length of the first greenhouse experiment. However, these concentrations may form in the sludge during processing. If some concentrations begin to form in the sludge treatment process, however, they could act as nuclei for larger concentrations in the soil. It was decided to do X-ray diffraction analyses and microscopic examination of sludges (See Section 7.4).

7.2 Characterization of Soils from the Field Grass Experiments

7.2.1 Objectives

To evaluate soil structure produced by sewage sludge applications on field plots. To evaluate the extent of movement into the soil of Ca, Fe and Al used in sludge treatments.

7.2.2 Methods and materials

After the last sludge application in September of 1974, surface soil layers from one plot of each sludge at the 1600 kg N/ha and 200 kg N/ha rates were sampled for thin section preparation. A soil profile to the depth of 12 inches (30 cm) was also taken from each plot for element analysis. Extra small blocks of the surface two inches were taken to use as test blocks for impregnation, as difficulties occurred with the greenhouse samples. Na-dithionite and NH_4-oxalate extractable elements were determined by methods referred to in Section 7.1.2.

7.2.3 Results and discussion

The Fe and Al-sludges at the 1600 kg N/ha rate had nearly continuous black surface layers. The Ca-sludge did not have a continuous surface layer. The soil surfaces of each plot were 40% covered by mosses at the time of sampling. The micromorphological features of each of the sewage sludges (Figure 5) were similar to that of the greenhouse soils (Figure 1). The movement of Fe-sludge and Al-sludge particles was not evident under the microscope. However, the Fe - P crystals were very evident in the Fe-sludge (Figure 5c). These crystals were decomposing under field conditions (Figure 5e). The movement downward of Ca sludge was evident by microscope (Figure 5d).

The distribution of Na-dithionite and NH_4-oxalate extractable Fe, Al and Mn to the depth of 12 inches (30 cm), for soils treated with Ca-sludge (Table 205), Al-sludge (Table 206) and Fe-sludge (Table 207), was similar to the untreated soils (Land Disposal of Sewage Sludge, Volume II, Table 27) except for the surface three inches (7.5 cm).

The 1600 kg N/ha Ca-sludge treatment reduced the Na-dithionite extractable Fe and Al down to three inches (7.5 cm), (Table 205). The 1600 kg N/ha Al-sludge treatment reduced Na-dithionite extractable Fe but increased extractable Al (Table 206) in the surface one inch (2.5 cm). NH_4-oxalate extractable Al was also much higher with the 1600 kg N/ha Al-sludge treatment (Table 206). There was an increase of Na-dithionite extractable Fe down to 2 inches (5 cm) with the 1600 kg N/ha rate of Fe-sludge (Table 207). The higher NH_4-oxalate extractable Fe within the 1600 kg N/ha rate of Fe-sludge (Table 207) does not correspond with the results on the greenhouse soils (Table 203). However, coupled with the evidence of the Fe - P crystals decomposing under field conditions (Figure 5e), this suggests that the Fe released from these crystals may be chelated by soil organic matter.

There was an increase in Na-dithionite extractable Ca with the 1600 kg N/ha rate over the 200 kg N/ha rate down to the 12 inch (30 cm) depth with the Ca-sludge (Table 208), Al-sludge (Table 209) and Fe-sludge (Table 210). The increase in Ca was greatest, as expected, with the Ca-sludge.

The NH_4-oxalate extractable Mg values with the Ca-sludge (Table 208) and Fe-sludge (Table 210) were, as expected with the 1600 kg N/ha rate, showing an increase at all depths. The Mg values with the Al-sludge (Table 209) cannot be explained at this time.

An increase in Na-dithionite extractable Zn occurred in the surface inch (2.5 cm) of the 1600 kg N/ha rate of the Al-sludge (Table 209) and the Fe-sludge (Table 210).

7.2.4 Conclusions

As the sludges were dried and rewetted during natural climatic conditions, the elemental "concentrations" found in the greenhouse experiments moved into the soil under field conditions. Ca moved further than Fe or Al, as expected. The Fe - P compounds are weathering under field conditions.

7.3 Micromorphological Characterization of Soils from Corn Plots and Runoff Plots

7.3.1 Objectives

To define the nature of micromorphological features present in the soils before any sewage sludge was applied.

7.3.2 Methods and materials

The methods of sampling, preparation of thin sections and microscopic examination have been reported (Land Disposal of Sewage Sludge, Volume II).

7.3.3 Results and discussion

Representative dominant micropedological features of one soil profile from each experimental plot are presented. The natural pedological features that may influence movement and/or ultimate location of sewage sludge constituents are identified within each soil (Figures 6, 7, 8 and 9).

The coarse particle size of the Caledon sandy loam soil profile results in large amounts of pore space and limited absorptive capacity. The finer particles coat sand grains in the Ah horizon (Figure 6a). The clay particles have been moved out of the Ae horizon, leaving many uncoated sand grains (Figure 6b). The clay particles have been illuviated to the Bt horizon and coat nearly all the sand grains (Figure 6c). The calcium has reprecipitated in the Cca horizon where various form of $CaCO_3$ minerals are found (Figure 6d).

The medium particle size of the Conestoga silt loam soil profile from the Elora corn plots results in less large pore spaces and a greater absorptive capacity. The Ah horizon is made up of small undefined aggregates (Figure 7a). The irregular thickness of solum in this soil profile results in very well defined iron-manganese concretions near leached parts of the solum and also near weathering dolomite fragments in the AB1 horizon (Figure 7b). The finer particle size and greater initial clay content (than in the Caledon soil profile) of the parent material results in argillans (clay akins) accumulating in larger pore spaces (voids) of the Bt horizon (Figure 7c). The fluctuating water table in this site results in faint iron-manganese concentrations next to dolomitic particles in the II BCg horizon (Figure 7d).

The high clay content of the Oneida clay loam soil profile from the Milton corn plots results in very few pores and argillans in the Ah horizon (Figure 8a). These are the reasons why this soil has a low infiltration rate and a high absorptive capacity. Water movement is dominantly along large pores (created during drying) which results in large amounts of illuviated clay lining these pores (Figure 8b). High water holding capacity of these soils results in the formation of iron-manganese concentrations in the BC horizon (Figure 8c). In the C horizon, calcium carbonate accumulates along the walls of large pores (Figure 8d).

The micromorphological features of the Conestoga sandy clay loam soil profile from the runoff plots (Figure 9) are very similar to those of the Conestoga silt loam from the corn plots. However, the Ae horizon (Figure 9b) is depleted of clay as compared to the Ah horizon (Figure 9a). Thus, in a single field of this type of soil, variability occurs and should be understood.

7.3.4 Conclusions

The micromorphological features demonstrate that natural processes result in a variable redistribution of cations in each of the soils being used for sewage sludge disposal. It is logical to look for heavy metals after years of sewage sludge application near natural micropedological features.

7.4 Characterization of Sludges

7.4.1 Introduction

The microscopic examination of sewage sludge in thin sections of soils (Section 7.1.3) revealed that each sludge may contain a substantial crystalline inorganic fraction prior to application on the soil.

It was decided to examine the nine sludges used in the second greenhouse experiment, as well as the three sludges used in the first greenhouse experiment, by X-ray diffraction and microscope analysis.

7.4.2 Objectives

To identify the inorganic and/or crystalline forms in the nine sewage sludges used in the second greenhouse experiment.

7.4.3 Methods and materials

The sludges were plated on 1 x 3 inch (2.5 x 7.5 cm) glass slides and X-ray diffraction patterns were collected after each of four pretreatments (air dry heating to 100°C, heating to 350°C, and heating to 550°C).

The slivers or fibres were isolated from one sludge sample by simple sieving and washing.

7.4.4 Results and discussion

The preliminary mineral identification revealed quartz in each sludge (Table 211). Feldspars, silicate minerals, and calcite were other soil occurring minerals found in these sludges. Some forms of iron and aluminum phosphates were present in some sludges, also some aluminum sulphates and aluminum silicate hydrates (Table 211). As the diffraction patterns were taken of the total sludge, definite identification of the complex iron, and aluminum phosphate hydrates was not possible. Fractionation of sludge samples prior to X-ray diffraction analyses should provide positive identification of most minerals.

Examination of isolated slivers under the microscope showed the various forms present in sludge (Figure 10). Higher magnification revealed mat and spiral forms (Figure 10b). An X-ray diffraction pattern of this material and infra-red patterns suggested that these are organic materials. It is assumed that these slivers or fibres probably originate from synthetic materials used in clothes.

7.4.5 Conclusions

There are inorganic mineral forms present in the sewage sludges after treatment at the sewage plants. The sewage sludges contain large amounts of particulate matters. It would be useful to definitively identify the particulate matter in sewage sludges.

7.5 Literature Cited

Jenne, E.A., J.W. Ball and C. Simpson. 1974. "Determination of Trace metals in sodium dithionite-citrate extracts of soils and sediments by atomic absorption". J. Environ. Quality, 3: 381-387.

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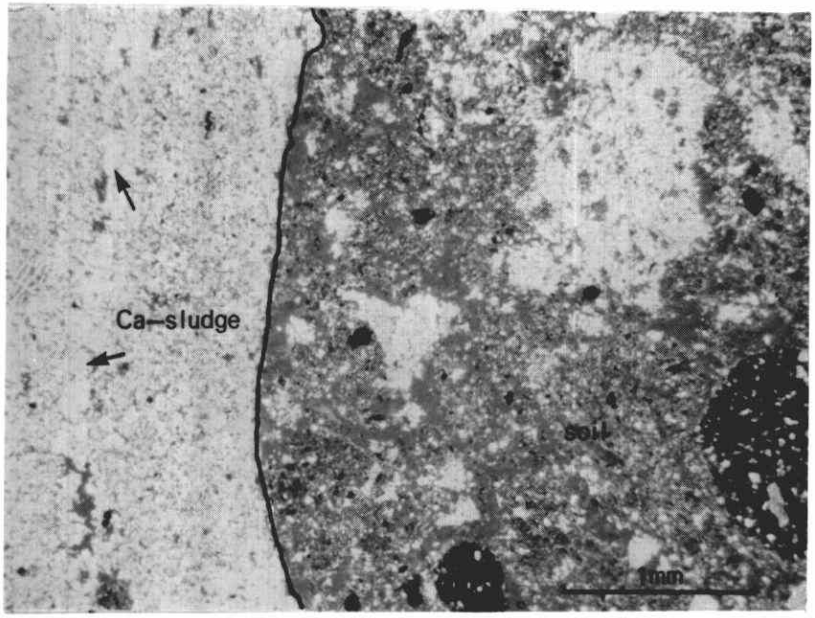
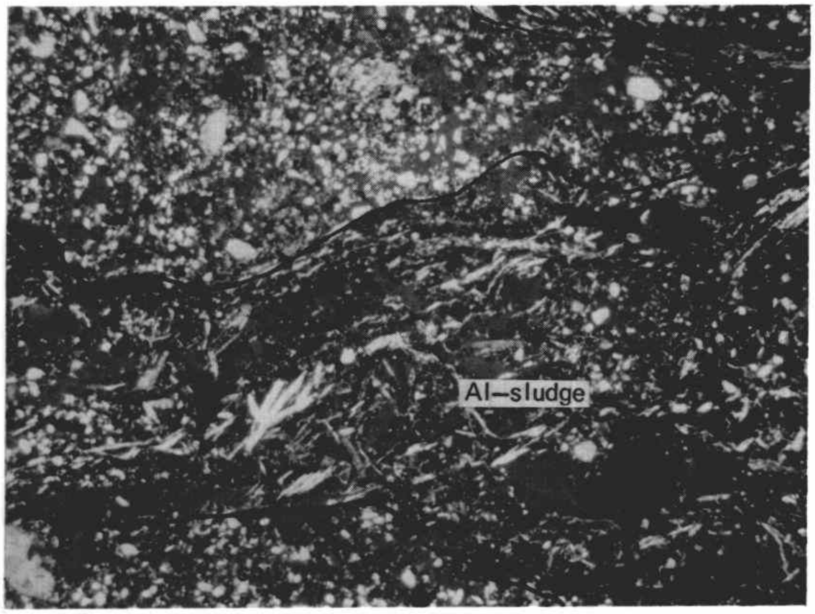
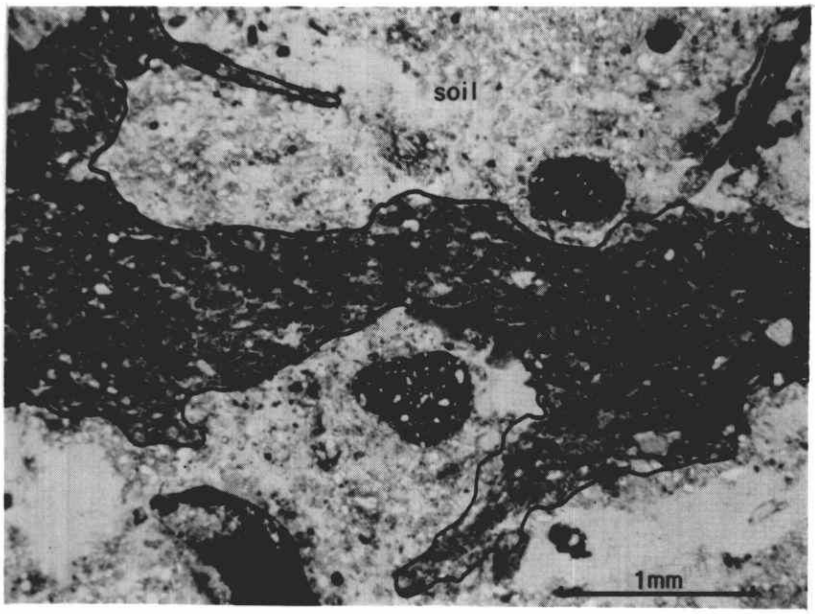


(a) Ca–sludge. Note recrystallization of Ca (presumably $CaCO_3$).

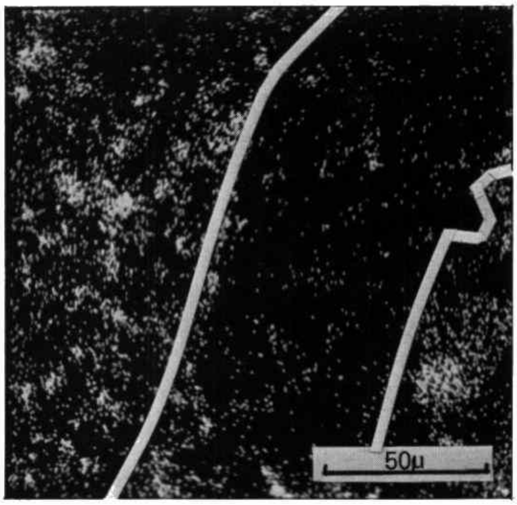


(b) Al–sludge. Note fibrous material in Al–sludge.

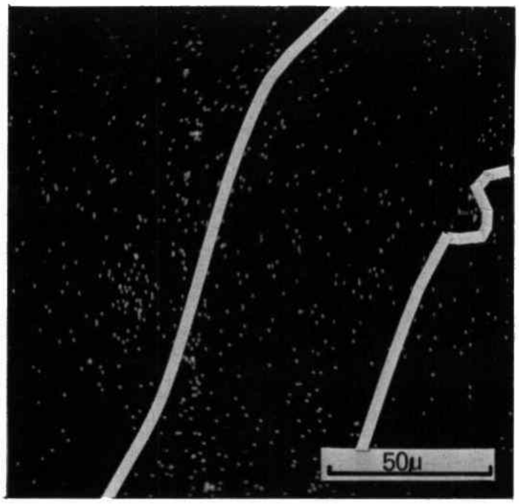


(c) Fe–sludge.

FIGURE 1 . REPRESENTATIVE MICROGRAPHS OF THE THREE SLUDGES IN THE FIRST GREENHOUSE EXPERIMENT



Si



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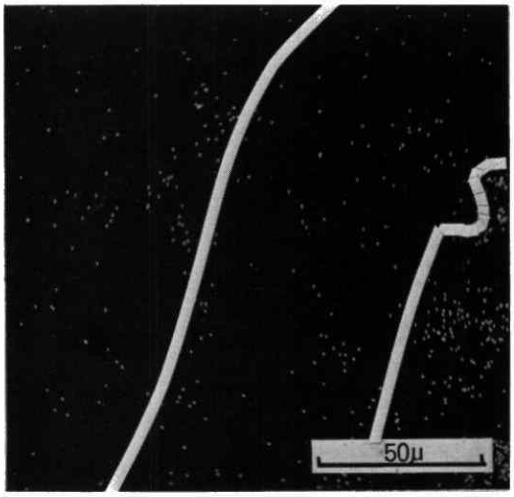
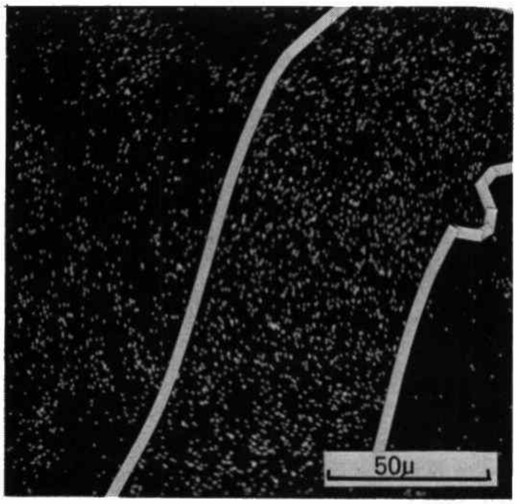
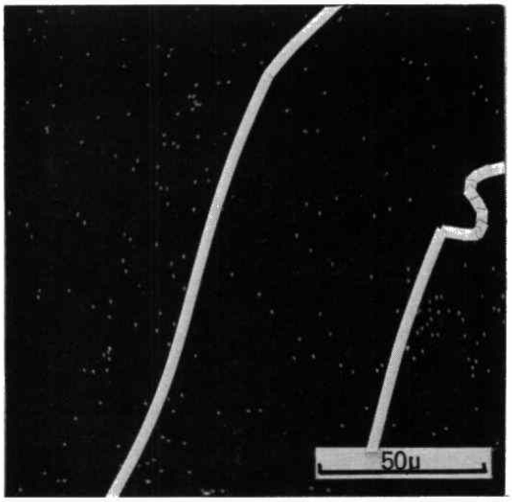


Al

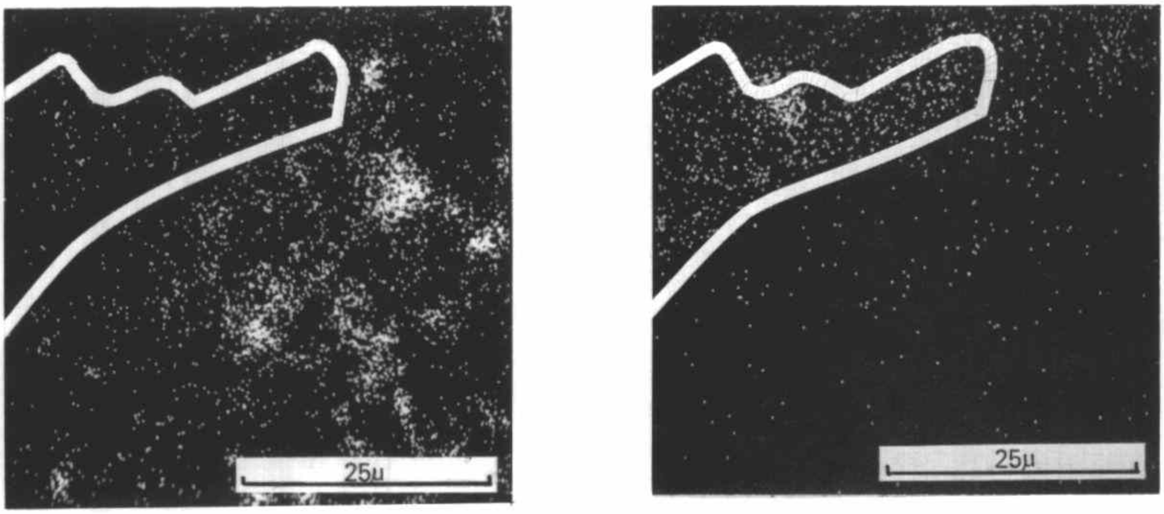


Ca



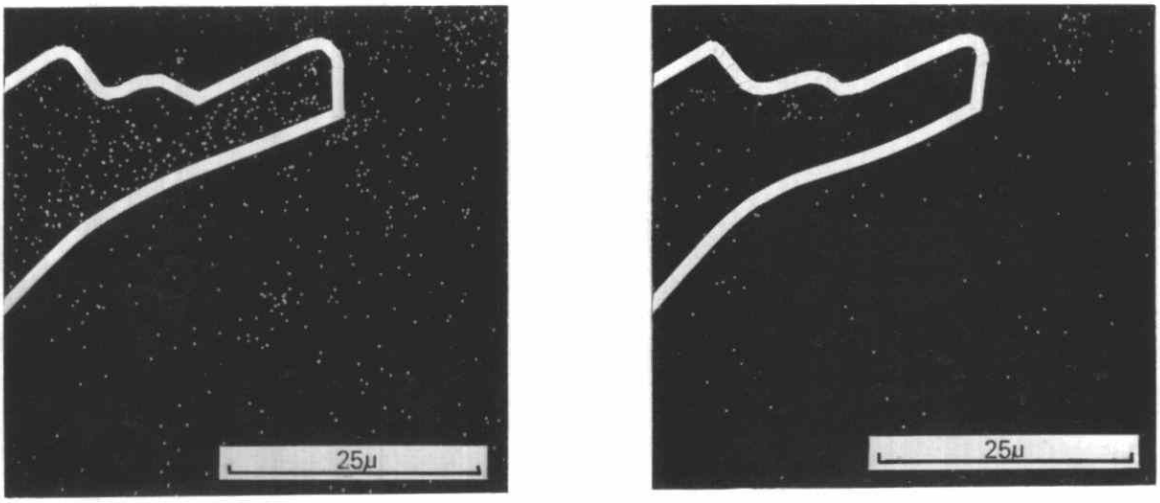
Fe

FIGURE 2. ELECTRON MICROPROBE MICROGRAPHS SHOWING THE DISTRIBUTION OF Si, P, Ca, Al AND Fe IN A Ca–SLUDGE PARTICLE



Si

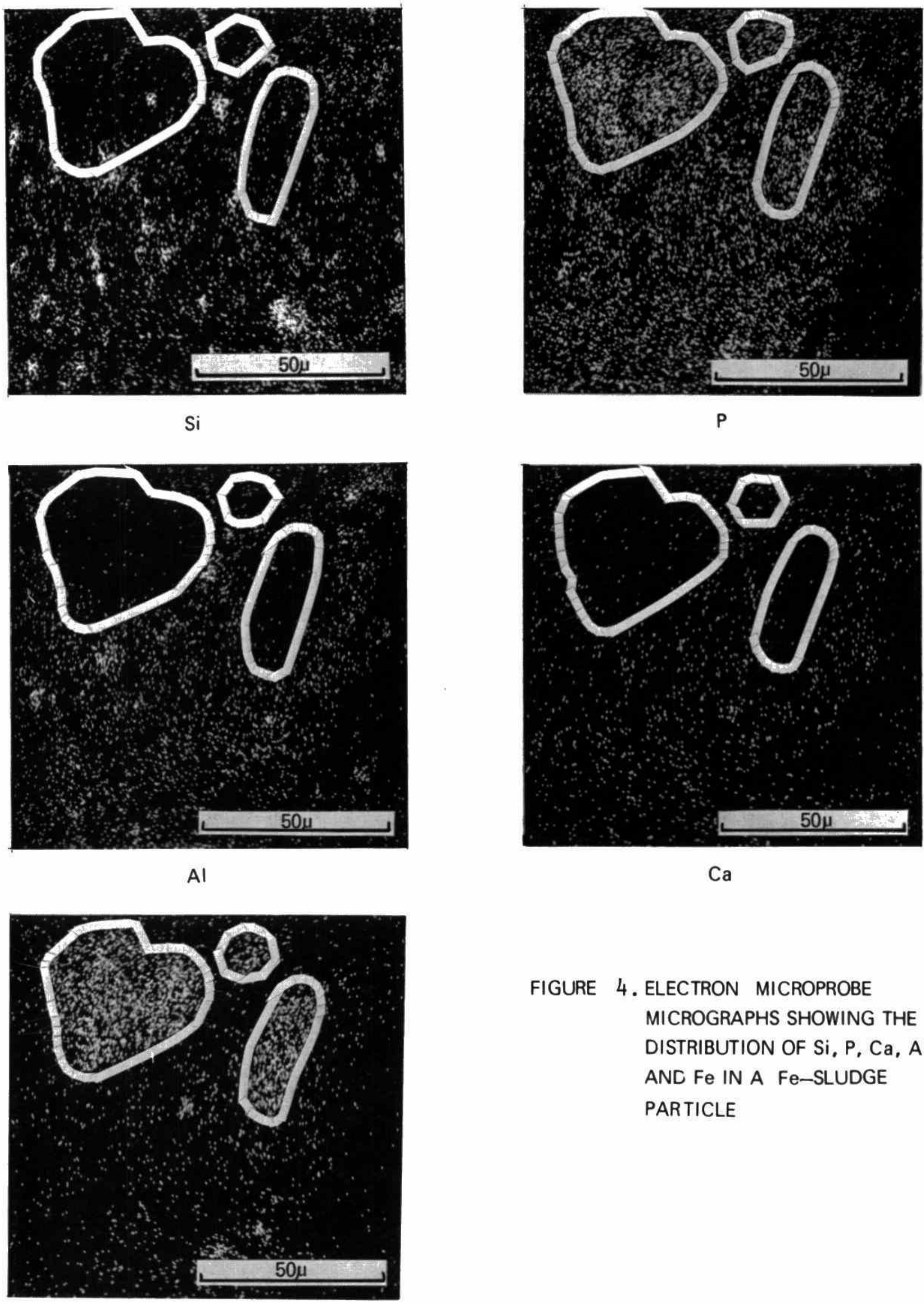
P



Al

Ca

FIGURE 3. ELECTRON MICROPROBE MICROGRAPHS SHOWING THE DISTRIBUTION OF Si, P, Al AND Ca IN AN Al–SLUDGE PARTICLE



Si

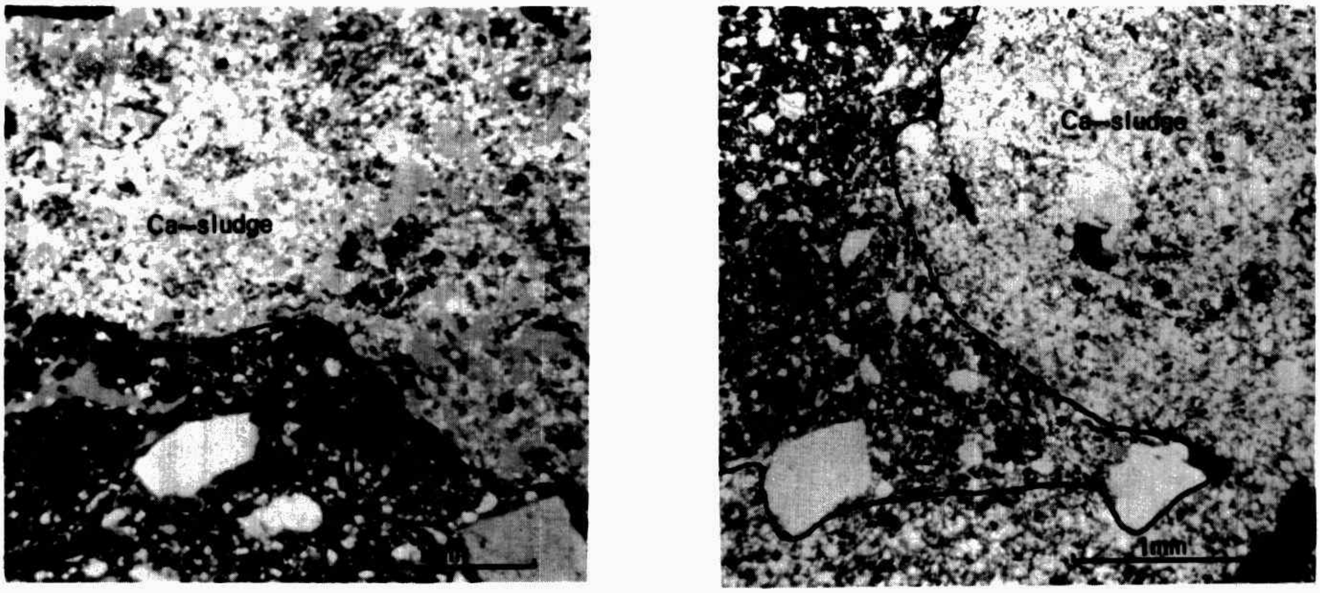
P

Al

Ca

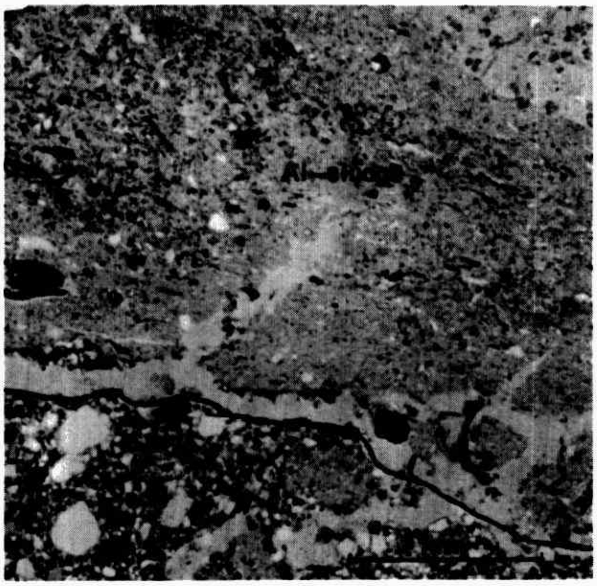
Fe

FIGURE 4. ELECTRON MICROPROBE MICROGRAPHS SHOWING THE DISTRIBUTION OF Si, P, Ca, Al AND Fe IN A Fe–SLUDGE PARTICLE



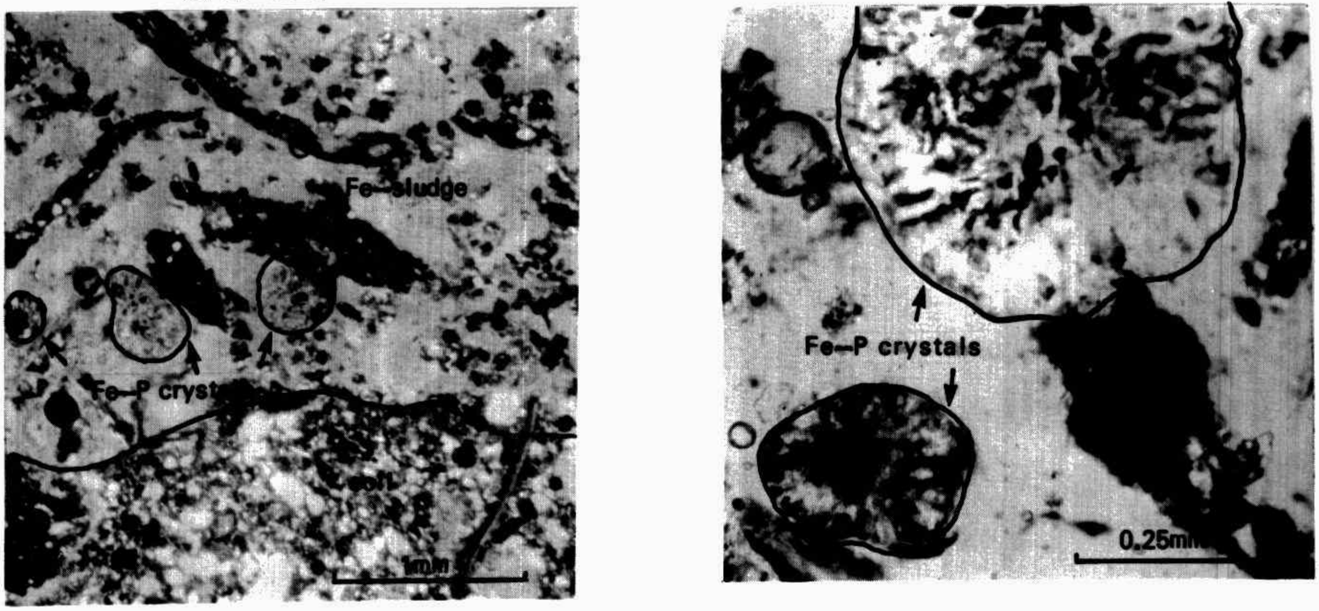
(a) Ca—sludge

(d) Ca—sludge at the 3 inch (7.5 cm) depth.



(b) Al—sludge

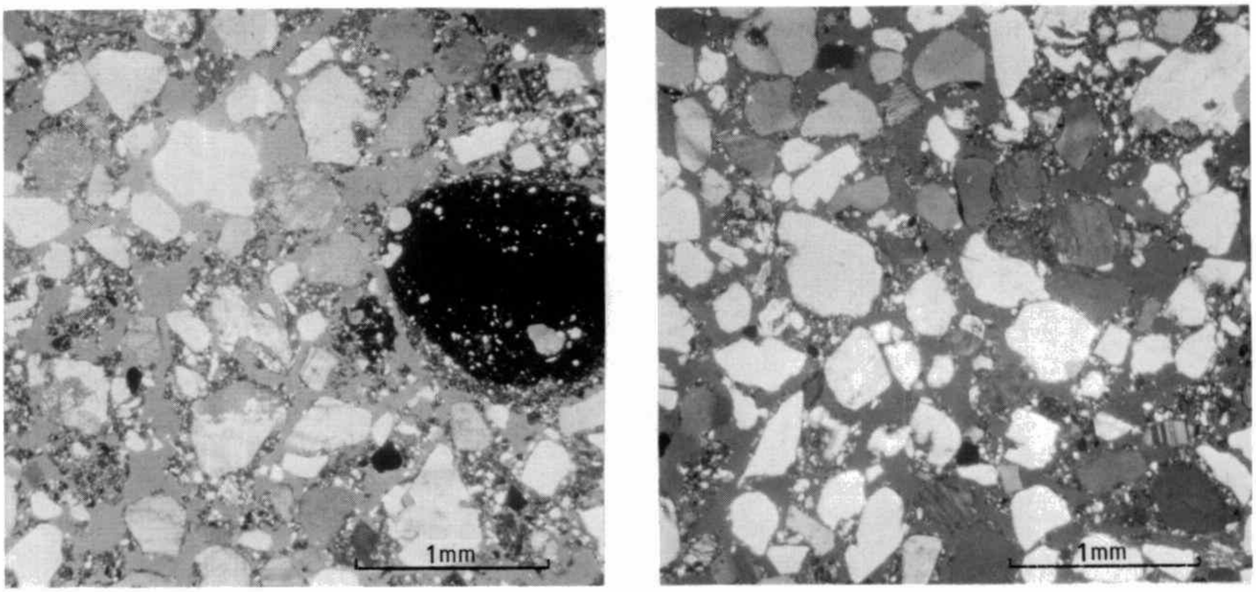
FIGURE 5. REPRESENTATIVE MICROGRAPHS OF THE INTERFACES BETWEEN THE SOIL AND THREE SLUDGES (1600 KgN/acre rates) FROM THE GRASS PLOTS



(c) Fe—sludge

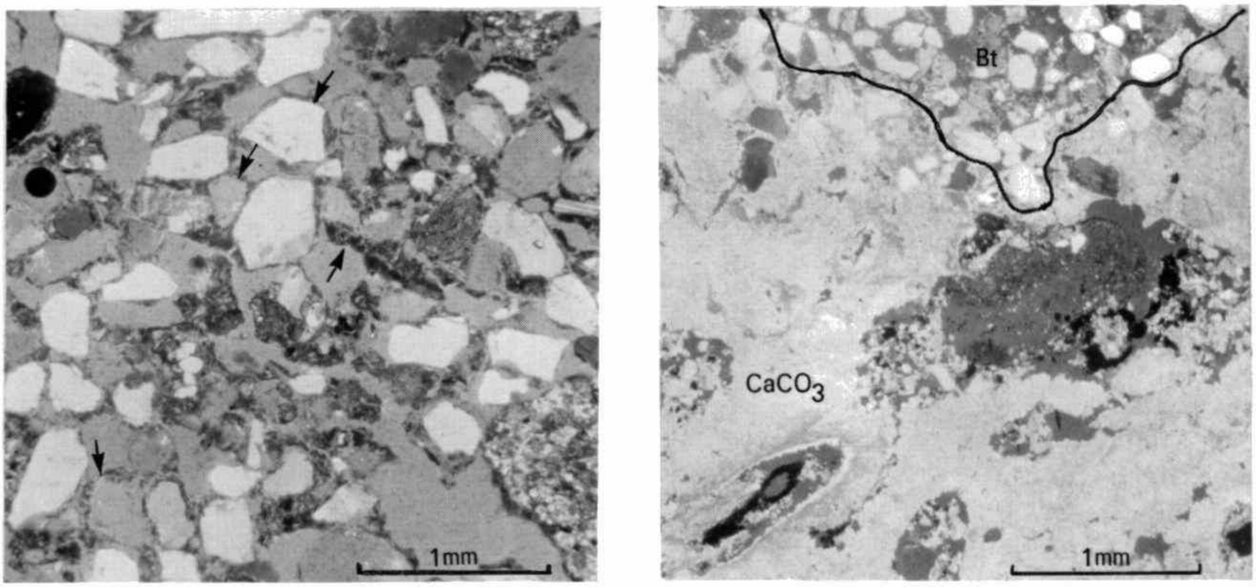
(e) Fe—sludge showing Fe—P compound.

FIGURE 6. REPRESENTATIVE MICROGRAPHS OF THE MAJOR HORIZONS OF THE CALENDON SANDY LOAM SOIL PROFILE FROM THE CAMBRIDGE CORN PLOTS



(a) Ah horizon. Horizontal section at the 3 inch (7 cm) depth. Note silt and clay matrix around each skeleton sand grain.

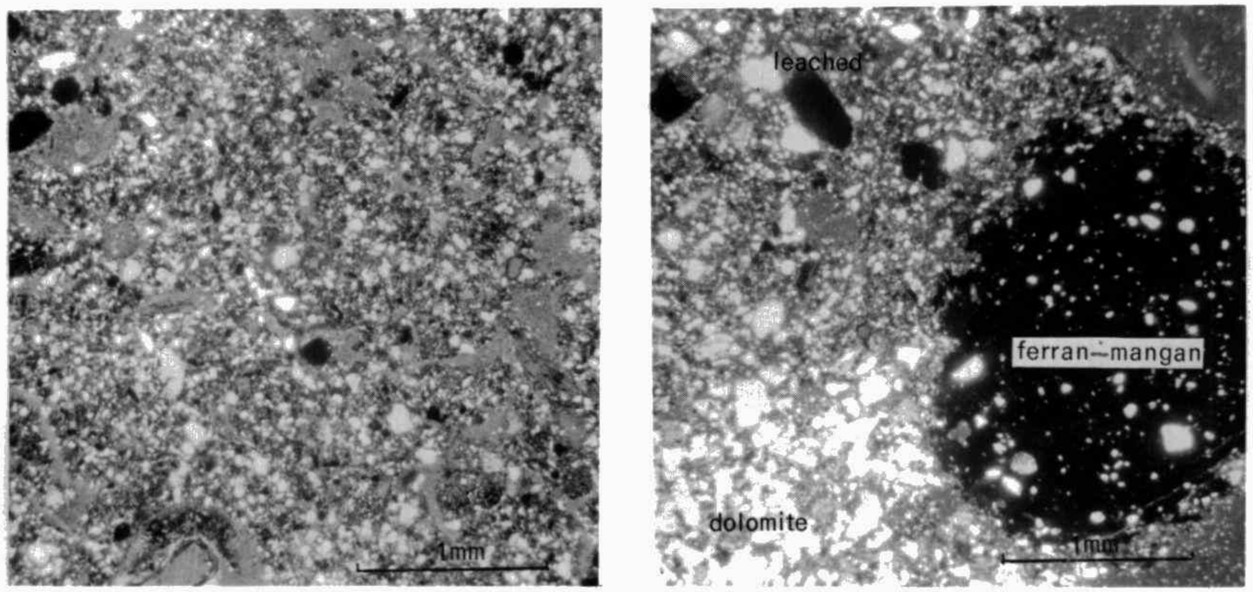
(b) Ae horizon. Horizontal section at the 9 inch (22 cm) depth. Note less silt and clay matrix around each skeleton sand grain.



(c) Bt horizon. Horizontal section at the 17 inch (43 cm) depth. Note argillans (clay skins) around each skeleton sand grain.

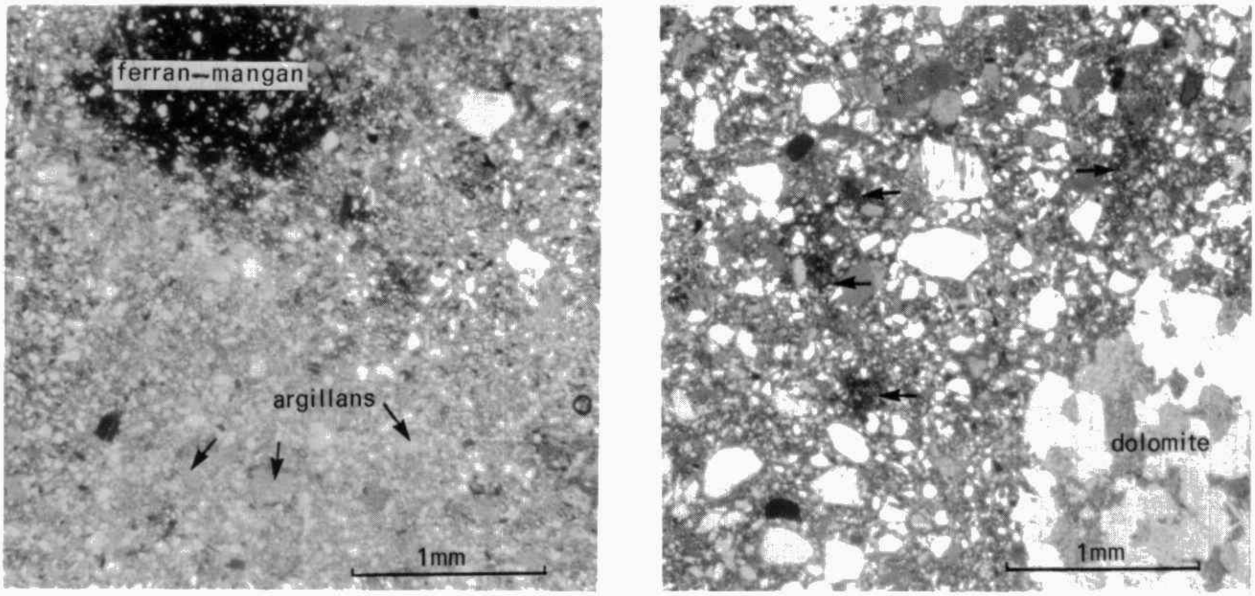
(d) Cca horizon. Horizontal section at the 62 inch (158 cm) depth. Note accumulation of $CaCO_3$ next to Bt horizon.

FIGURE 7. REPRESENTATIVE MICROGRAPHS OF THE MAJOR HORIZONS OF THE CONESTOGA SILT LOAM SOIL PROFILE FROM THE ELORA CORN PLOTS



(a) Ah horizon. Horizontal section at the 3 inch (7 cm) depth. Note the well formed aggregates.

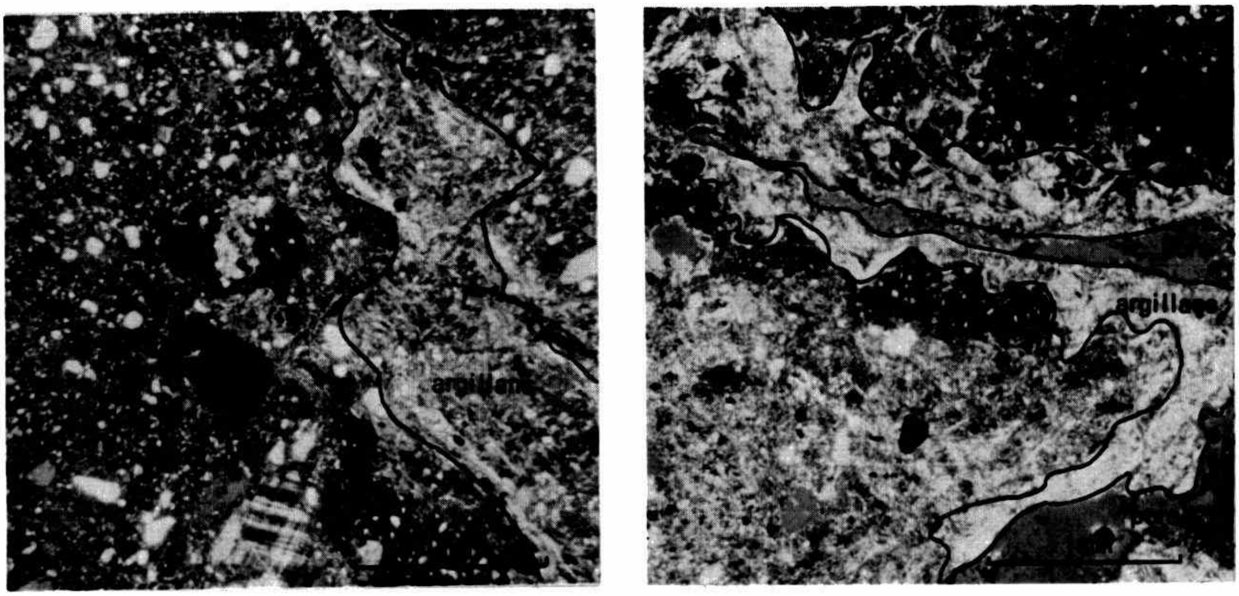
(b) AB2 horizon. Horizontal section at the 15 inch (38 cm) depth. Note ferran–mangan in association with dolomite and leached area.



(c). Btjg horizon. Horizontal section at the 21 inch (54 cm) depth. Note ferran– mangan and argillans.

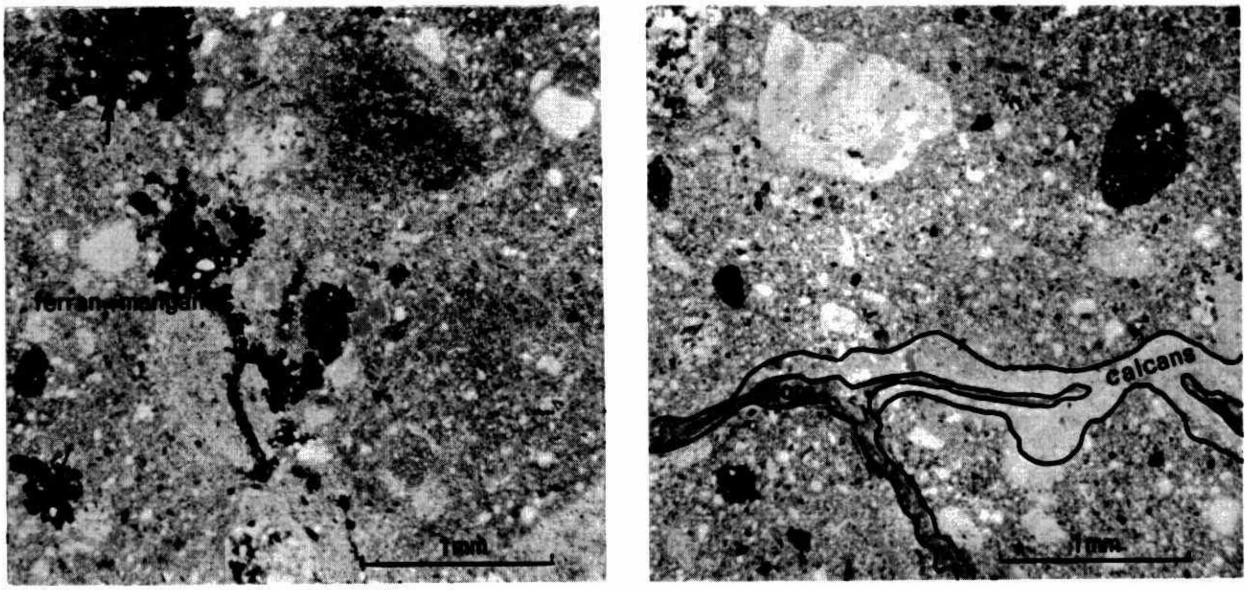
(d) II BCg horizon. Horizontal section at the 30.5 inch (77 cm) depth. Note small ferran–mangans and dolomite.

FIGURE 8. REPRESENTATIVE MICROGRAPHS OF THE MAJOR HORIZONS OF THE ONEIDA CLAY LOAM SOIL PROFILE FROM THE MILTON CORN PLOTS



(a) Ah horizon . Horizontal section at the 3.5 inch (9 cm) depth. Note mixture of argillans (clay skins) with other material.

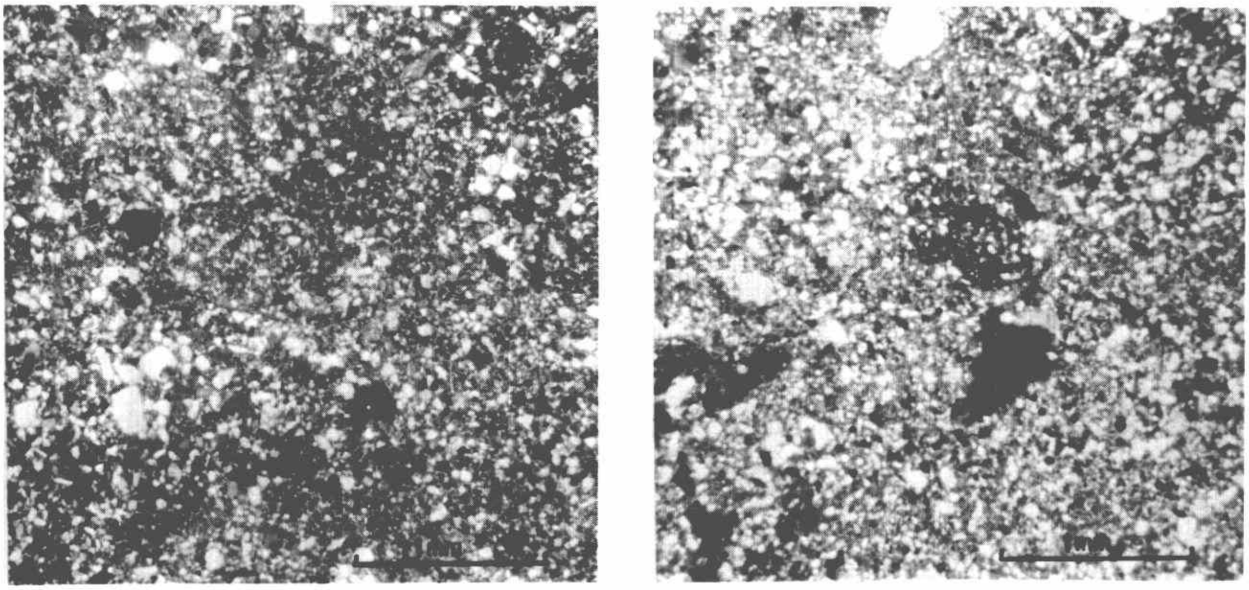
(b) Bt 1 horizon. Horizontal section at the 9.5 inch (24 cm) depth. Note massive argillans on pore walls and lack of sand grains.



(c) BC horizon. Horizontal section at the 17 inch (43 cm) depth. Note large amounts of silt and clay in dense matrix, ferran and mangans.

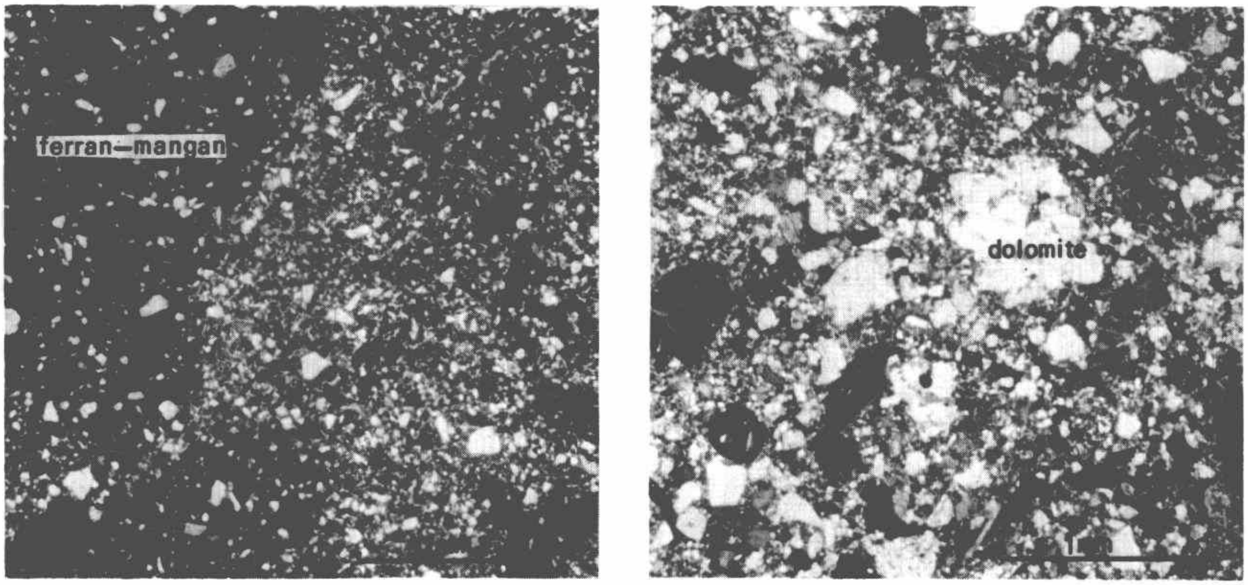
(d) C horizon. Horizontal section at the 30 inch (76 cm) depth. Note calcans ($CaCO_3$) along pore walls and increased amounts of coarse sand in dense matrix.

FIGURE 9. REPRESENTATIVE MICROGRAPHS OF THE MAJOR HORIZONS OF THE CONESTOGA SANDY CLAY LOAM SOIL PROFILE FROM THE RUNOFF PLOTS



(a) Ah horizon. Horizontal section at the 8.5 inch (21 cm) depth. Note matrix is made up of fine sand, silt and clay.

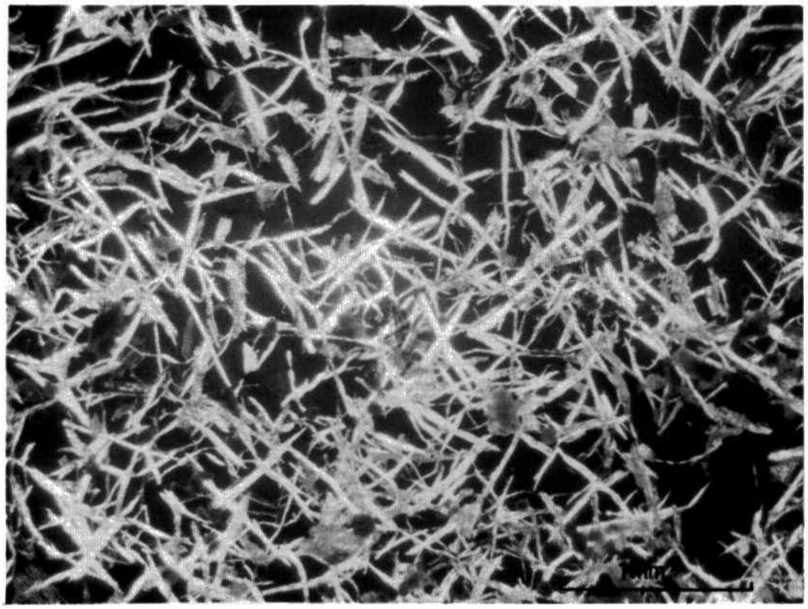
(b) Ae horizon. Horizontal section at the 15 inch (38 cm) depth. Note decrease of clay.



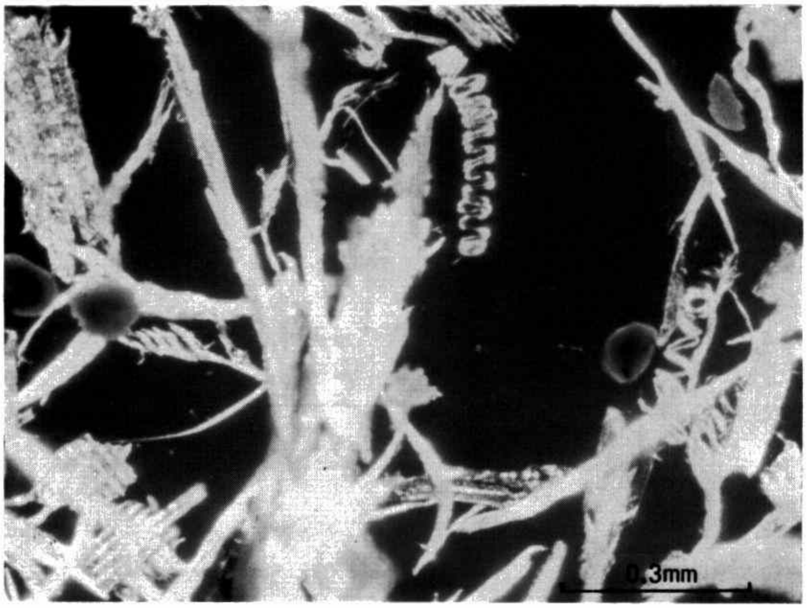
(c) Bmg horizon. Horizontal section at the 20.5 inch (52 cm) depth. Note the ferran–mangan nodules and lack of argillans (clay skins).

(d) IVCKg horizon. Horizontal section at the 38.5 inch (98 cm) depth. Note primary dolomitic sand particles and uncoated pore walls.

FIGURE 10. MICROGRAPHS OF SLIVERS IN SLUDGE



(a) Slivers in sludge



(b) Enlargement of slivers. Note mats and spirals.

TABLE 203. Na-dithionite and NH$_4$-oxalate Extractable Fe, Al and Mn in Soils of Selected Treatments from the First Greenhouse Study.

Sludge Treatment	pH	Na-dithionite (%)			NH$_4$-oxalate (%)		
		Fe	Al	Mn	Fe	Al	Mn
		Clay Loam					
Check	5.5	1.64	.24	.13	.79	.23	.11
	7.5	1.64	.23	.12	.85	.19	.10
Fe-sludge (5000 kg N/ha)	5.5	2.44	.41	.14	.77	.24	.08
	7.5	2.44	.27	.12	.88	.29	.10
Ca-sludge (5000 kg N/ha)	5.5	1.63	.22	.11	.62	.15	.07
	7.5	1.48	.18	.12	.39	.15	.07
Al-sludge (5000 kg N/ha)	5.5	1.64	.76	.11	.63	.54	.08
	7.5	1.60	.58	.11	.64	.54	.08
		Sandy Loam					
Check	5.5	1.01	.21	.10	.62	.22	.07
	7.5	1.03	.20	.10	.47	.17	.07
Fe-sludge (5000 kg N/ha)	5.5	1.46	.40	.11	.88	.34	.08
	7.5	1.42	.39	.11	.88	.30	.07
Ca-sludge (5000 kg N/ha)	5.5	.84	.16	.08	.43	.15	.06
	7.5	.92	.18	.07	.37	.15	.05
Al-sludge (5000 kg N/ha)	5.5	1.03	.80	.13	.51	.48	.08
	7.5	.84	.61	.07	.51	.58	.06

TABLE 204. Na-dithionite Extractable Ca, Mg and Zn and NH_4-oxalate Extractable Mg in Soils of Selected Treatments from First Greenhouse Study.

Sludge Treatment	pH	Na-dithionite (%) Ca	Na-dithionite (%) Mg	Na-dithionite (%) Zn	NH_4-oxalate (%) Ca	NH_4-oxalate (%) Mg
			Clay Loam			
Check	5.5	.26	.03	.004	N.D.*	.24
	7.5	1.54	.02	.005	N.D.	.11
Fe-sludge (5000 kg N/ha)	5.5	.45	.04	.005	N.D.	.27
	7.5	1.20	.03	.004	N.D.	.22
Ca-sludge (5000 kg N/ha)	5.5	2.29	.06	.004	N.D.	2.68
	7.5	2.29	.05	.004	N.D.	3.24
Al-sludge (5000 kg N/ha)	5.5	.58	.05	.005	N.D.	.82
	7.5	1.87	.03	.005	N.D.	.64
			Sandy loam			
Check	5.5	.08	.004	.004	N.D.	.03
	7.5	.56	.003	.004	N.D.	.02
Fe-sludge (5000 kg N/ha)	5.5	.40	.03	.005	N.D.	.15
	7.5	.75	.02	.005	N.D.	.17
Ca-sludge (5000 kg N/ha)	5.5	2.09	.04	.004	N.D.	3.38
	7.5	2.18	.05	.004	N.D.	3.36
Al-sludge (5000 kg N/ha)	5.5	.47	.03	.005	N.D.	.25
	7.5	.76	.02	.005	N.D.	.19

* N.D. - Not Determined.

TABLE 205. Na-dithionite and NH_4-oxalate Extractable Fe, Al and Mn from the Ca-sludge Treated Grass Plots.

Depth Inches (cm)	Na-Dithionite (%)						NH_4-Oxalate (%)					
	200 kg N/ha			1600 kg N/ha			200 kg N/ha			1600 kg N/ha		
	Fe	Al	Mn	Fe	Al	Mn	Fe	Al	Mn	Fe	Al	Mn
0- 1 (0-2.5)	1.25	.16	.06	.92	.07	.04	.30	.22	.05	.37	.12	.03
1- 2 (2.5-5.0)	1.29	.17	.06	.90	.07	.04	.32	.20	.05	.35	.13	.03
2- 3 (5.0-7.5)	1.37	.17	.06	1.15	.12	.06	.33	.26	.05	.36	.21	.03
3- 4 (7.5-10.0)	1.37	.17	.06	1.23	.13	.07	.40	.27	.07	.35	.22	.04
4- 5 (10.0-12.5)	1.25	.17	.07	1.22	.15	.06	.14	.23	.05	.30	.21	.04
5- 6 (12.5-15.0)	1.29	.16	.07	1.21	.15	.06	.32	.22	.05	.39	.27	.04
6- 8 (15.0-20.0)	1.41	.23	.08	1.15	.16	.05	.28	.22	.05	.33	.22	.04
8-10 (20.0-25.0)	1.31	.18	.07	1.21	.13	.04	.23	.17	.04	.19	.13	.02
10-12 (25.0-30.0)	1.17	.15	.07	1.25	.12	.03	.08	.10	.06	.10	.12	.02

TABLE 206. Na-dithionite and NH_4-oxalate Extractable Fe, Al and Mn from the Al-sludge Treated Grass Plots

Depth Inches (cm)	Na-dithionite (%)						NH_4-oxalate (%)					
	200 kg N/ha			1600 kg N/ha			200 kg N/ha			1600 kg N/ha		
	Fe	Al	Mn	Fe	Al	Mn	Fe	Al	Mn	Fe	Al	Mn
0- 1 (0-2.5)	1.15	.20	.06	.96	1.58	.04	.33	.29	.04	.49	1.93	.03
1- 2 (2.5-5.0)	1.17	.17	.06	1.11	.27	.06	.29	.20	.05	.33	.32	.05
2- 3 (5.0-7.5)	1.20	.15	.07	1.23	.18	.06	.32	.21	.04	.31	.21	.04
3- 4 (7.5-10.0)	1.25	.16	.07	1.19	.18	.06	.29	.18	.05	.32	.21	.04
4- 5 (10.0-12.5)	1.15	.15	.06	1.21	.18	.06	.30	.20	.06	.31	.20	.03
5- 6 (12.5-15.0)	1.23	.16	.06	1.24	.17	.06	.32	.21	.06	.27	.22	.04
6- 8 (15.0-20.0)	1.15	.15	.06	1.19	.15	.06	.31	.17	.05	.34	.20	.05
8-10 (20.0-25.0)	1.13	.15	.07	1.27	.17	.06	.24	.14	.04	.36	.24	.02
10-12 (25.0-30.0)	1.15	.14	.07	1.35	.18	.07	.25	.14	.06	.40	.23	.06

TABLE 207. Na-dithionite and NH_4-oxalate Extractable Fe, Al and Mn from the Fe-sludge Treated Grass Plots.

Depth Inches (cm)	Na-Dithionite (%)						NH_4-Oxalate (%)					
	200 kg N/ha			1600 kg N/ha			200 kg N/ha			1600 kg N/ha		
	Fe	Al	Mn	Fe	Al	Mn	Fe	Al	Mn	Fe	Al	Mn
0- 1 (0-2.5)	1.35	.18	.06	2.44	.40	.07	.48	.23	.06	2.2	.47	.04
1- 2 (2.5-5.0)	1.29	.18	.07	1.54	.24	.07	.33	.18	.05	.81	.27	.04
2- 3 (5.0-7.5)	1.27	.17	.07	1.39	.18	.06	.34	.22	.06	.44	.21	.04
3- 4 (7.5-10.0)	1.35	.18	.08	1.50	.20	.07	.31	.21	.07	.39	.23	.05
4- 5 (10.0-12.5)	1.23	.17	.08	1.35	.19	.07	.36	.25	.07	.34	.21	.04
5- 6 (12.5-15.0)	1.25	.15	.07	1.35	.16	.08	.31	.20	.05	.15	.21	.04
6- 8 (15.0-20.0)	1.21	.15	.06	1.39	.18	.07	.29	.17	.03	.34	.21	.04
8-10 (20.0-25.0)	1.29	.16	.07	1.43	.18	.07	.28	.17	.04	.39	.24	.04
10-12 (25.0-30.0)	1.41	.16	.08	1.58	.18	.06	.31	.20	.04	.43	.24	.04

TABLE 208. Na-dithionite Extractable Ca, Mg and Zn and NH_4-oxalate Extractable Mg from the Ca-sludge Treated Grass Plots.

Depth Inches (cm)	Na-dithionite (%)						NH_4-oxalate (%)	
	200 kg N/ha			1600 kg N/ha			200 kg N/ha	1600 kg N/ha
	Ca	Mg	Zn	Ca	Mg	Zn	Mg	Mg
0- 1 (0-2.5)	1.07	.04	.005	2.15	.07	.005	.94	1.48
1- 2 (2.5-5.0)	.68	.04	.005	2.15	.07	.005	.78	1.66
2- 3 (5.0-7.5)	.61	.05	.005	1.41	.06	.006	.90	1.00
3- 4 (7.5-10.0)	.56	.04	.005	1.87	.06	.006	.76	.96
4- 5 (10.0-12.5)	.62	.05	.005	1.51	.06	.005	.84	.82
5- 6 (12.5-15.0)	.59	.05	.005	1.09	.06	.006	.86	1.00
6- 8 (15.0-20.0)	.59	.05	.006	.92	.05	.005	.86	.74
8-10 (20.0-25.0)	.41	.04	.006	.63	.04	.005	.62	.64
10-12 (25.0-30.0)	.25	.03	.005	.52	.05	.006	.46	.60

TABLE 209. Na-dithionite Extractable Ca, Mg and Zn and NH_4-oxalate Extractable Mg from the Al-sludge Treated Grass Plots.

Depth Inches (cm)	Na-dithionite (%)						NH_4-oxalate (%)	
	200 kg N/ha			1600 kg N/ha			200 kg N/ha	1600 kg N/ha
	Ca	Mg	Zn	Ca	Mg	Zn	Mg	Mg
0- 1 (0-2.5)	.54	.05	.005	1.87	.07	.009	1.11	1.30
1- 2 (2.5-5.0)	.46	.05	.005	.64	.05	.006	1.17	.93
2- 3 (5.0-7.5)	.47	.05	.005	.55	.05	.006	1.32	1.02
3- 4 (7.5-10.0)	.47	.05	.005	.54	.06	.005	1.25	.97
4- 5 (10.0-12.5)	.43	.04	.005	.56	.05	.005	1.55	.90
5- 6 (12.5-15.0)	.43	.04	.005	.55	.05	.006	1.51	.94
6- 8 (15.0-20.0)	.35	.05	.005	.57	.05	.005	2.12	1.04
8-10 (20.0-25.0)	.39	.05	.005	.55	.05	.005	1.82	.90
10-12 (25.0-30.0)	.31	.004	.005	.53	.06	.005	.71	.92

TABLE 210. Na-dithionite Extractable Ca, Mg and Zn and NH_4-oxalate Extractable Mg from the Fe-sludge Treated Grass Plots.

Depth Inches (cm)	Na-dithionite (%)						NH_4-oxalate (%)	
	200 kg N/ha			1600 kg N/ha			200 kg N/ha	1600 kg N/ha
	Ca	Mg	Zn	Ca	Mg	Zn	Mg	Mg
0- 1 (0-2.5)	.77	.05	.006	1.21	.09	.010	1.04	1.92
1- 2 (2.5-5.0)	.58	.05	.005	.77	.07	.006	.78	1.38
2- 3 (5.0-7.5)	.58	.05	.005	.66	.07	.005	.96	1.20
3- 4 (7.5-10.0)	.53	.05	.005	.66	.07	.006	.90	1.18
4- 5 (10.0-12.5)	.53	.05	.005	.68	.06	.006	.94	1.00
5- 6 (12.5-15.0)	.55	.05	.005	.77	.06	.006	.92	1.84
6- 8 (15.0-20.0)	.55	.05	.005	.74	.06	.006	.80	1.18
8-10 (20.0-25.0)	.55	.05	.005	.67	.06	.006	.86	1.04
10-12 (25.0-30.0)	.36	.05	.005	.55	.06	.006	.78	.74

TABLE 211. Preliminary Identification of X-Ray Diffraction Data on Twelve Sludges used in the Two Greenhouse Studies

Sludge	Treatment	Quartz	Feldspar	Calcite	Silicate Clays	Iron Phosphate Hydrate	Aluminum Phosphate Hydrate	Aluminum Sulphate Hydrate	Aluminum Silicate Hydrate
				1st Greenhouse Study					
North Toronto	$FeCl_3$	x	<	<		<		x	
Newmarket	Lime	x	x	x		x			
Point Edward	Alum	x		<			<		
				2nd Greenhouse Study					
Guelph	none	x		x	x		<		
Fergus	none	x			x		x		x
Toronto Humber	none	x	<		<		<	<	
Aurora	none	x		x	x				
Point Edward	$FeCl_3$	x		x		<		x	
Sarnia	$FeCl_3$	x	<	x	x	<	<	<	
North Toronto	$FeCl_3$	x				<		x	
Newmarket	lime	x		x		x	<		
Midland	lime	x	<	x	<	<			

x - mineral dominant

< - mineral present

8. GENERAL DISCUSSION AND CONCLUSIONS

8.1 Runoff

In general, nitrogen losses in runoff were low, with the highest amounts being lost from plots receiving sludge in mid-January. One runoff event immediately following fall sludge application resulted in elevated values for losses of nitrogen, phosphorus, metals and COD. With the exception of this one event, phosphorus losses were low, and metal and COD losses were low and did not differ between treatments.

8.2 Crop Growth

8.2.1 In the field

In general, in the field trials crop growth was at least as good with sludges as with chemical fertilizers. The three chemically treated sludges produced similar yields although the iron sludge tended to advance early growth and maturity of corn slightly. There was no evidence of poor growth with the aluminum sludge in 1974 in any of the trials, the apparent toxic effect of Point Edward sludge on grass in 1973 having dissipated. Crop yields in 1974 responded to nitrogen application from ammonium nitrate and from sewage sludge.

8.2.2 In the greenhouse

In the first crop in the greenhouse, all sludges appeared to increase yields, but when applied at high rates of application, four of the sludges produced appreciably lower yields than when applied at lower rates. In the second crop, all the sludges except one produced low yields when applied at high rates. It has now been shown that soil salinity was at least part of the problem. In future, soil will be leached in this experiment after each sludge addition. Salinity is not likely to be a problem in the field in Ontario at moderate rates of application but could pose a serious problem with the use of at least some of these sludges in dry areas of Western Canada.

8.3 Nutrient and Metal Availability

8.3.1 Soil pH

The calcium sludge tended to increase soil pH in the field and greenhouse even on soil of pH 7.1. The aluminum and iron sludges lowered soil pH, but less than one quarter as much as similar rates of nitrogen from ammonium nitrate.

8.3.2 Nitrogen

In general, about twice as much nitrogen appeared to be required from sludge as from ammonium nitrate to produce a particular yield or nitrogen content in grass or corn in the field in 1974. One might expect that, as each year passes, the sludge nitrogen would compare more favourably with ammonium nitrate due to the accumulation of organic matter and the gradual release of nitrogen from it. Nitrate nitrogen concentrations in grass and corn stover approached toxic levels for animals at the highest rates of sludge application.

8.3.3 Phosphorus

Sludges increased sodium bicarbonate extractable ("plant available") phosphorus in soil quite markedly. This effect was appreciably greater with the calcium sludge although it supplied less total phosphorus than the other sludges in most cases. Phosphorus concentration in crops was slightly higher with the calcium than with the other sludges, but even the lowest rates of sludges produced adequate phosphorus concentrations in plants and increasing rates of sludge did not, in general, increase phosphorus concentrations.

The phosphorus in calcium sludge appears to be appreciably more available in Ontario soils than that supplied in iron or aluminum sludges. With the large amounts of phosphorus in sludge, this greater availability may be a disadvantage where sludges are applied repeatedly to the same land.

8.3.4 Boron

The Midland sludge supplied appreciably more boron than other sludges and could pose a toxicity problem if used at high rates for certain crops, or if used in dry areas where boron could accumulate.

8.3.5 Cadmium

Cadmium concentrations were quite low in the field trials but the use of high cadmium sludges in the greenhouse resulted in appreciable uptake. Of particular concern was the high cadmium concentration in the second crop of grass on the treatment, which received only one application of sludge at the 1600 kg N/ha rate before the first crop was seeded. This produced higher cadmium concentrations than two applications of 1600 kg N/ha, one before seeding each crop. Thus, cadmium appeared to become more available with time after application.

8.3.6 Copper

Copper concentrations were increased by sludge applications, increases being, in general, related to copper additions. The sludges which were used in the field trials were low in copper. They increased copper content of crops but no more than the increase with ammonium nitrate.

8.3.7 Nickel

Nickel concentrations in crops increased quite markedly with addition of nickel in sludges. The calcium sludge from Midland, high in nickel, increased concentrations of nickel in ryegrass quite markedly even at high soil pH. Nickel, like cadmium, appeared to become more available with time.

8.3.8 Zinc

Zinc concentrations were increased by sludge additions in the field and greenhouse, although in the greenhouse some low zinc sludges also reduced zinc concentrations in grass, probably by raising soil pH. At high rates of application, zinc appeared to become more available with time after application in sludge.

8.3.9 Other nutrients and metals

Potassium, calcium, magnesium, manganese, iron, aluminum, chromium and mercury concentrations in crops were all significantly affected by treatment in one or more trials but effects were variable and small. There was no evidence that aluminum sludges produced high aluminum concentrations in crops. Chromium concentrations in crops increased quite appreciably on a percentage basis in one trial but the concentrations were still quite low.

8.4 Nitrogen

In the field trials, less nitrate accumulated in the soil under grass than under corn. More nitrate appeared to be produced by sludges containing the largest portion of their nitrogen in ammonium form. In general, nitrate concentrations in soil solution were quite high, but movement was less than in 1973, probably due to the lower rainfall in July and August in 1974. The nitrate concentrations were much greater in the silt loam and clay loam profiles than in the sandy loam, for reasons that are not clear. In the fall of 1973, nitrate appeared to be lost from the clay loam profile, probably by denitrification, but in 1974 there was no apparent loss.

In laboratory nitrification studies, nitrate production continued for at least 52 weeks. The rate of nitrate production varied among sludges but differences were not related to chemical treatment applied to sewage for phosphate control or to ammonium content. The Point Edward aluminum sludge collected in 1973 gave a low rate of nitrate production. The Point Edward iron sludge collected in 1974 also gave a low rate of nitrate production, although not as low as the 1973 sludge.

8.5 Soil Tests for Metals

Comparisons of various chemical extractants as measures of metal availability to plants show acetic acid as a promising extractant for nickel. Further work is required on the other metals.

8.6 Soil Characterization

Iron in the iron sludge is crystallized, based on chemical extraction, microprobe analysis and X-ray. Where the sludges have been applied on the soil surface in the bromegrass trial, the ferric phosphate crystals appear to be decomposing and the iron may chelate with organic matter.

Where the sludge has been surface applied, calcium, aluminum and iron all appear to be moving into the soil but calcium has moved the farthest, up to twelve inches in two years.

Examination of the sludges before application to soil show inorganic minerals and particulate matter. Some fibrous material in the aluminum sludge appears to be organic.

9 MICROBIOLOGY

9.1 Introduction

Since May, 1973, an attempt has been made to establish the numbers of some groups of indicator bacteria in runoff waters and sludges and to determine the presence or absence of such pathogenic types as members of the genera *Salmonella* and *Shigella* in sludges, runoff waters, and on plant material harvested from plots receiving these sludges.

To date, there have been sixteen runoff events in this study. This has involved the examination of duplicate portions from 352 samples. Duplicate portions of 39 samples of digestor sludge have also been examined.

In 1974, samples of corn and grass from check plots and plots receiving the greatest amounts of the sludges at the three stations were examined.

Sludge and runoff water samples continue to be submitted to the Ontario Ministry of Health for the detection of viruses.

9.2 Methods

9.2.1 Sludge and runoff waters

Samples of these have been examined as soon as possible following the application or collection. Since the spring of 1974, the amount of such materials examined for the presence-absence of *Salmonella Shigella* has been 250 grams in the case of sludges, and 250 ml in the case of runoff waters. Such amounts were added to duplicate flasks of three selective enrichment media. The flow diagram will indicate the details of this examination (Figure 11).

The most probable numbers of coliforms and faecal coliforms continue to be estimated by a multiple tube dilution procedure using Lauryl Tryptose Broth and Brilliant Green Bile Broth at 37°C, and EC Broth at 44.5°C. The most probable number of faecal streptococci is being estimated by a multiple tube procedure with KF Streptococcus Broth.

For a time in 1974, the examination of runoff waters was restricted to samples from 10 of 22 plots. At present, samples from all plots are being examined.

9.2.2 Corn and grass samples

The corn plant samples were obtained from the three research stations at the time of thinning. Samples were also obtained from a site remote from the application of sludges.

At the research stations, the plants were obtained from each of three plots receiving the three sludges at 1424 lb N/ac (1600 kg N/ha), and from the three plots which had received ammonium nitrate at 178 lb N/ac (200 kg N/ha).

Corn plant samples were also obtained from three sites on an Elgin County farm. This land had never received domestic waste digestor sludge, but had received animal manure and chemical fertilizer.

The grass samples were obtained from each of the three plots receiving the sludges at 1424 lb N/ac and the ammonium nitrate at 178 lb N/ac at the Elora Research Station.

In the 1974 season, the plant material was collected, cut into short sections and distributed in 50 gram amounts to duplicate flasks of three selective enrichment media. The media presently being used are:

Tetrathionate Broth (Difco #0491)
Selenite Br. Green Sulfa Broth (Difco #0715)
GN Broth (Difco #0486)

The primary plating media presently in use are:

MacConkey Agar (Difco #0075)
Br. Green Sulfa Agar (Difco #0717)
Hektoen Enteric Agar (Difco #0853)
S.S. Agar (Difco #0074)

9.3 Results

9.3.1 Sludges and runoff waters

Tables 212 to 225 provide some idea of the numbers of indicator organisms encountered in the sludges and runoff waters.

North Toronto sludge is being applied to the runoff plots. Obviously, large numbers of the indicator organisms have been added. A comparison of the numbers present in the sludge and runoff waters indicates a great reduction. This could be brought about by dilution, retention at the soil-sludge location, loss of viability since application or a combination of all these factors.

The incidence of high and low values of total coliforms, faecal coliforms and faecal streptococci in runoff waters, as obtained from Tables 218 to 225, could suggest:

1) That the variation in total coliform numbers is such that they are of little value as indicators of the quality of runoff water from the test plots involved here. The abundance of these organisms in the applied sludge is evident in Table 212. In spite of this, the highest counts of coliforms occurred with water from check plots after three of the eight runoff events between April/74 and March/75. Although the greatest number of coliforms occurred in waters from sludge treated plots obtained during the remaining runoff events, runoff waters from the fall application plots failed to register a maximum count for any of these eight runoff events.

2) That the incidence of faecal coliforms is too low and irregular to serve as a reliable indication of the quality of runoff water from the test plots. The lack of faecal coliforms is consistent with the absence of *Salmonella-Shigella* types.

3) That the incidence of faecal streptococci in runoff waters appears, at times, to be related to the presence of sludge. Results of the examination of runoff waters from plots receiving sludge at the rate of 178 lb N/ac on the 6% slope suggest a possible relationship between the presence of sludge and the greater number of faecal streptococci. However, the results of the examination of runoff waters from plots receiving sludge at both rates on the 2% slope are not consistent with this relationship.

9.3.2 Idenfification of isolates

9.3.2.1 Runoff waters. Over 400 isolates have been obtained from all runoff events up to November 1, 1974. Two of these have been identified as *Salmonella enteriditis*. The remainder are not *Salmonella* or *Shigella* species. The two isolates of *S. enteriditis* were isolated from runoff water of August 2, 1973. This plot, on a 6% slope, had received a spring application of sludge at the rate of 178 lb N/ac.

A large number of isolates have been accumulated from the six runoff events which have occurred since January 1, 1975. These have not yet been screened for identification.

9.3.2.2 Sludges. Some 261 samples have been examined since May/73 from 33 samples. Eight samples were found to contain *Salmonella enteriditis* and one contained a species of *Shigella*. Table 226 indicates the source of these isolates.

A few isolates from one sample of sludge received January/75 have not yet been examined.

9.3.2.3 Corn plants. Of 400 isolates obtained in 1973 and 1974 from 87 samples, none was identified as *Salmonella* or *Shigella* species.

9.3.2.4 Grass. Of 310 isolates obtained in 1973 and 1974 from 60 samples, four have been identified as *Salmonella enteriditis*. These were isolated from samples harvested from plot 8 and plot 65 at the time of the third cutting, August 26, 1974. Plot 8 received iron sludge at the rate of 1600 kg N/ha. Plot 65 received lime sludge at the rate of 1600 kg N/ha. Grass from two plots of the nine treated with sludge at this rate yielded *Salmonella sp.*

9.3.3 Efficiency of isolation procedures

According to the results of an experiment conducted in 1974, the method used in the detection of *Salmonella* will demonstrate the presence of approximately one cell of *S. enteriditis* in 25 g of grass and sludge with SBG, BG and TT enrichment broths as the selective media.

Shigella sonnei was not recovered from similarly prepared and inoculated flasks.

9.4 Comments

1. *Salmonella* species have been isolated from sludge (9 of 39 samples), runoff waters (1 of 352 samples) and grass (2 of 60 samples).

2. The presence of *Salmonella* species in grass and corn, or even runoff water is, of course, not necessarily related to sludge applied to that plot.

3. *Salmonella-Shigella* species were not detected on any of the corn samples examined.

4. The numbers of indicator organisms present in runoff waters are much less than those present in sludge. If any of these, and particularly the faecal coliforms, are considered to be indicative of the survival of *Salmonella-Shigella* species, then the absence of such pathogens from runoff water is to be expected.

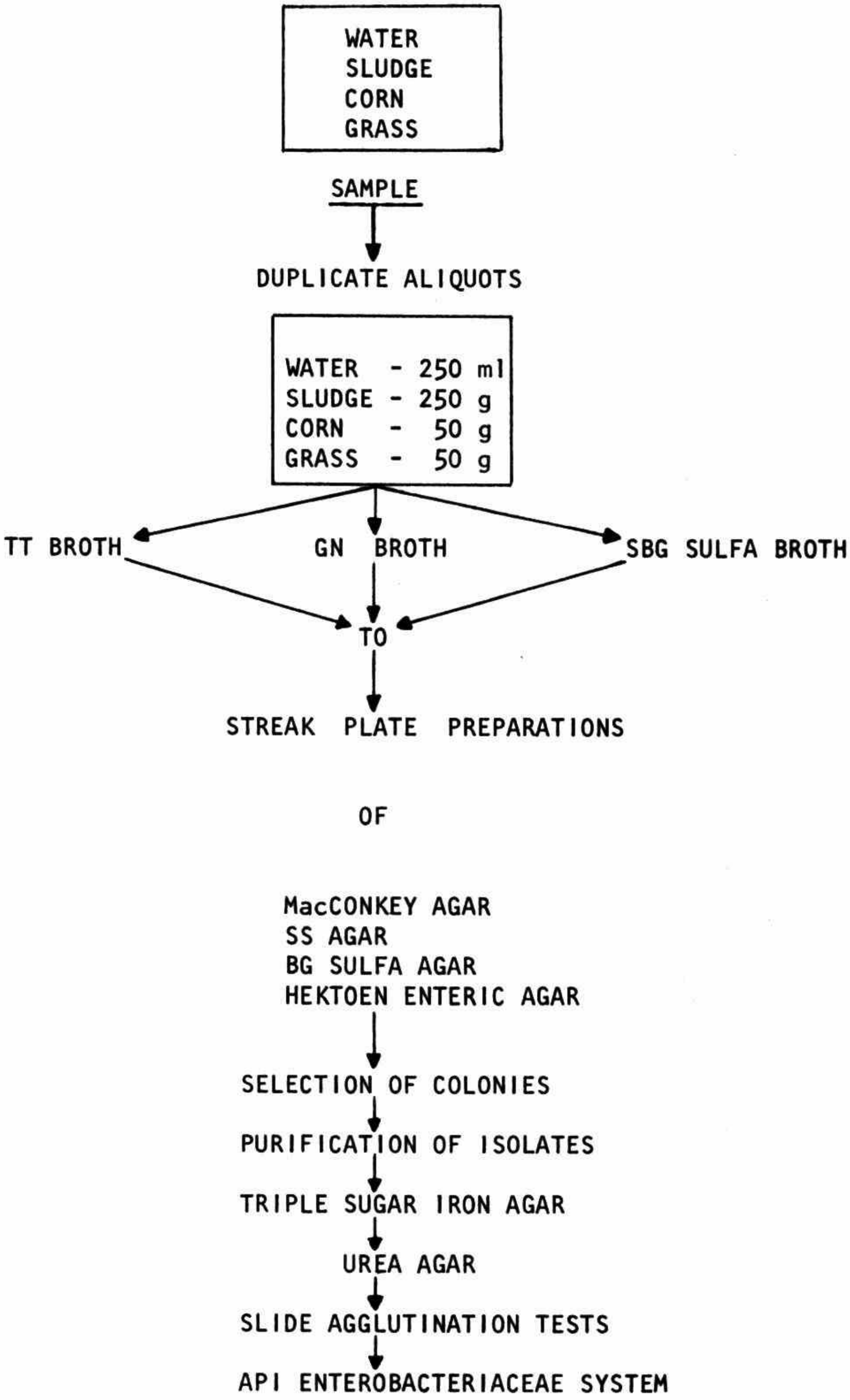


FIGURE 11. DETECTION OF *SALMONELLA - SHIGELLA*

TABLE 212. Number* of Some Indicator Organisms in North Toronto Iron-treated Sludge

	Samples of:						
Microorganisms	April 30/74	May 2/74	May 24/74	June 20/74	July 25/74	Nov. 19/74	Jan. 15/75
Total Coliforms	200,000	12,500	45,000	1,200,000	1,550,000	1,260,000	260,000
Faecal Coliforms	37,000	200	0	500,000	550,000	107,000	126,000
Faecal Streptococci	16,000,000	1,900,000	1,600,000	11,000,000	8,320,000	73,000	24,000

*Estimate per 100 g MPN procedure.

TABLE 213. Number* of Some Indicator Organisms in Newmarket Lime-treated Sludge

	Samples of:						
Microorganisms	April 24/74	April 26/74	May 2/74	May 16/74	May 29/74	June 19/74	July 25/74
Total Coliforms	315,000	1,090,000	40,000	24,000	3,500,000	725,000	3,350,000
Faecal Coliforms	2,000,000	650,000	6,400	3,000	13,000	390,000	13,000
Faecal Streptococci	1,200,000	3,500,000	16,000,000	180,000	445,000	10,700,000	445,000

*Estimates per 100 g MPN procedure.

TABLE 214. Number* of Some Indicator Organisms in Kitchener Alum-treated Sludge

	Samples of:					
Microorganisms	April 17/74	April 18/74	May 1/74	May 8/74	June 20/74	July 25/74
Total Coliforms	895,000	140,000	600,000	33,000	2,145,000	6,000,000
Faecal Coliforms	210,000	48,000	32,000	0	2,145,000	1,200,000
Faecal Streptococci	3,900,000	2,950,000	2,400,000	450,000	5,400,000	940,000

*Estimates per 100 g MPN procedure.

TABLE 215. Number of Some Indicator Organisms in North Toronto Sludge (Iron) over a Period of Fifteen Months and Twelve Samples.

	Number of Organisms/100 grams		
	Maximum	Average	Minimum
Total Coliforms	19,500,000	2,174,000	12,500
Faecal Coliforms	2,400,000	306,000	0
Faecal Streptococci	16,000,000	4,812,000	295,000

TABLE 216. Number of Some Indicator Organisms in Newmarket Sludge (Lime) over a Period of Fifteen Months and Twelve Samples.

	Number of Organisms/100 grams		
	Maximum	Average	Minimum
Total Coliforms	16,000,000	5,520,750	24,000
Faecal Coliforms	4,500,000	757,000	3,000
Faecal Streptococci	3,500,000	2,646,000	29,000

TABLE 217. Number of Some Indicator Organisms in Kitchener Sludge (Alum) over a Period of Six Months and Six Samples.

	Number of Organisms/100 grams		
	Maximum	Average	Minimum
Total Coliforms	2,145,000	1,635,000	33,000
Faecal Coliforms	2,145,000	604,000	0
Faecal Streptococci	5,400,000	2,091,000	295,000

TABLE 218. Average Numbers of Indicator Organisms in Runoff Waters of April 2, 1974.

	Time of Sludge Application										
			Fall		Winter		Spring		Fall	Winter	Spring
	Sludge rate - lb N/ac (kg/ha)										
	None		178 (200)		178 (200)		178 (200)		714(800)	714(800)	714(800)
	Slope of Soil Surface										
Microorganisms	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
	Most probable number of organisms/100 ml										
Total Coliforms	65,000	805,000	2,300	455,000	130,000	417,000	19,000	51,000	58,000	104,000	12,000
Faecal Coliforms	2	1	4	0.5	0	0	1.5	2.5	1.5	0	1
Faecal Streptococci	2,400	9,100	2,300	27,000	32,000	37,000	16,000	140,000	3,000	5,000	2,100

TABLE 219. Average Numbers of Indicator Organisms in Runoff Waters of May 17, 1974.

	Time of Sludge Application										
			Fall		Winter		Spring		Fall	Winter	Spring
	Sludge rate - lb N/ac (kg/ha)										
	None		178 (200)		178 (200)		178 (200)		714(800)	714(800)	714(800
	Slope of Soil Surface										
Microorganisms	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
Total Coliforms	100	93	60	1,200	1,650	2,500	200	795	90	340	220
Faecal Coliforms	0	0	0	10	0	0	0	32	0	0	0
Faecal Streptococci	1,100	790	250	28,500	1,300	8,000	700	2,400	650	4,450	1,600

TABLE 220. Average Numbers of Indicator Organisms in Runoff Waters of January 30, 1975.

	Time of Sludge Application										
			Fall		Winter		Spring		Fall	Winter	Spring
	Sludge rate - lb N/ac (kg/ha)										
	None		178 (200)		178 (200)		178 (200)		714(800)	714(800)	714(800)
	Slope of Soil Surface										
Microorganisms	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
	Most probable number of organisms/100 ml										
Total Coliforms	400	8,100	5,800	3,700	600	9,900	6,600	28,600	2,200	1,100	950
Faecal Coliforms	0	0	0	0	0	0	0	1.5	0	0.5	0
Faecal Streptococci	3,600	2,200	400	1,100	300	5,000	860	1,000	1,300	48	700

TABLE 221. Average Numbers of Indicator Organisms in Runoff Waters of February 23, 1975.

	Time of Sludge Application										
			Fall		Winter		Spring		Fall	Winter	Spring
	Sludge rate - lb N/ac (kg/ha)										
	None		178 (200)		178 (200)		178 (200)		714(800)	714(800)	714(800)
	Slope of Soil Surface										
Microorganisms	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
Total Coliforms	8,200	1,100	2,700	86	73,00	1,100	5,000	300	3,400	3,000	4,900
Faecal Coliforms	50	1	0	0	0	2	0	0	0	0	0
Faecal Streptococci	2,000	200	5,400	230	2,400	950	920	290	2,400	5,300	1,500

TABLE 222. Average Numbers of Indicator Organisms in Runoff Waters of February 24, 1975.

	Time of Sludge Application										
			Fall		Winter		Spring		Fall	Winter	Spring
	Sludge rate - lb N/ac (kg/ha)										
	None		178 (200)		178 (200)		178 (200)		714(800)	714(800)	714(800)
	Slope of Soil Surface										
Microorganisms	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
Total Coliforms	49,000	460,000	48,000	18,000	28,000	15,500	1,800	49,600	11,000	75,000	265,000
Faecal Coliforms	1	0	0	0	0	0	0	0	0	0	0
Faecal Streptococci	1,800	290	180	150	60	1,700	1,000	600	3,800	3,700	67

TABLE 223. Average Numbers of Indicator Organisms in Runoff Waters of March 14, 1975.

	Time of Sludge Application										
			Fall		Winter		Spring		Fall	Winter	Spring
	Sludge rate - lb N/ac (kg/ha)										
	None		178 (200)		178 (200)		178 (200)		714 (800)	714 (800)	714 (800)
	Slope of Soil Surface										
Microorganisms	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
	Most probable number of organisms/100 ml										
Total Coliforms	39,000	4,500	49,000	1,000	-	4,400	126,000	7,100	44,000	22,000	34,000
Faecal Coliforms	0	0	0	0	-	0	0	0	0	0	0
Faecal Streptococci	62	33	53	190		290	790	32	210	81	510

TABLE 224. Average Numbers of Indicator Organisms in Runoff Waters of March 20, 1975.

	Time of Sludge Application										
			Fall		Winter		Spring		Fall	Winter	Spring
	Sludge rate - lb N/ac (kg/ha)										
	None		178 (200)		178 (200)		178 (200)		714 (800)	714 (800)	714 (800)
	Slope of Soil Surface										
Microorganisms	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
	Most probable number of organisms/100 ml.										
Total Coliforms	630	2,300	1,500	1,200	130	125,000	151,000	908,000	220	55,000	720
Faecal Coliforms	0	0	0	0	0	0	0	1.5	0	0	0
Faecal Streptococci	86	15	47	66	32	460	48	460	70	73	33

TABLE 225. Average Numbers of Indicator Organisms in Runoff Waters of March 23, 1975.

	Time of Sludge Application										
			Fall		Winter		Spring		Fall	Winter	Spring
	Sludge rate - lb N/ac (kg/ha)										
	None		178 (200)		178 (200)		178 (200)		714 (800)	714 (800)	714 (800)
	Slope of Soil Surface										
Microorganisms	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
	Most probable number of organisms/100 ml										
Total Coliforms	35,000	26,700	26,500	8,400	1,500	16,200	4,000	59,000	2,000	8,000	6,500
Faecal Coliforms	0	0	0	0	0	0	0	0	0	0	0
Faecal Streptococci	530	140	280	98	200	1,700	47	480	300	2,000	140

TABLE 226. Number of Sludge Samples Found to Contain *Salmonella* or *Shigella* Species.

Sludge Source	Samples Examined*	Samples Positive
North Toronto	12	4 (*S. enteriditis*)
Point Edward	3	1 (*Shigella sp.*)
Newmarket	12	1 (*S. enteriditis*)
Kitchener	6	3 (*S. enteriditis*)

* Includes samples May/73 to July/74.

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: volume III, (April, 1974 -
March, 1975) /
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